Risk-Informed, Performance-Based Regulatory Implications of

Improved Emergency Diesel Generator Reliability

Shantel M. Utton

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Signature of Author . . . .
Department of Nuclear Engineering
January 16, 1998

Certified by . . . .
Professor Michael W. Golay
Thesis Supervisor

Certified by . . . .
Professor Neil E. Todreas
Thesis Reader

Accepted by . . . .
Professor Lawrence M. Lidsky
Chairman, Department Committee on Graduate Students

RISK-INFORMED, PERFORMANCE-BASED REGULATORY IMPLICATIONS OF IMPROVED EMERGENCY DIESEL GENERATOR RELIABILITY

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ABSTRACT

The Nuclear Regulatory Commission's (NRC) steady progress towards risk-informed performance-based regulation (RIPBR) prompted the practical application of this regulatory tool in order to demonstrate its potential benefits. This practical demonstration makes up one part of an Idaho National Engineering and Environmental Laboratory (INEEL) sponsored project entitled *Integrated Models, Data Bases and Practices Needed for Performance-Based Safety Regulation.* Project members selected the emergency diesel generator system as a candidate for assessment because of its high risk importance for core damage frequency (CDF) as well as for its failure to exhibit fulfillment of its current maintenance objectives.

An analysis of current NRC maintenance and inspection requirements of the emergency diesel generators at the Millstone 3 nuclear power plant was performed by the project members. Maintenance and inspection items identified as unnecessary or harmful to the EDG qualified as candidates for removal from the current surveillance schedule. Expert testimony and comparisons with similar non-nuclear utility industries aided in the identification of candidate items.

Calculations of the subsequent risk, reliability, safety, and economic implications revealed several benefits of the inspection alterations. The modified inspection provided improved backup power availability and defense in depth during the refueling outage. A sensitivity analysis performed on the EDG basic events affected by inspection alteration showed that a 50% reduction in these basic event failure rates would decrease the EDG system failure probability by 13.9%. The altered inspection also shortens the plant's refueling outage critical path therefore decreasing the risk of fuel damage and improving the risk profile of the plant outage. Transfer of the revised inspection to performance while the plant is operating at power resulted in identical refueling outage benefits. Performance of the inspection at power requires an increase in the allowed outage time (AOT) of the plant. The subsequent rise in core damage frequency due to the increased AOT is considered negligible.

Thesis Supervisor: Michael W. Golay
Title: Professor of Nuclear Engineering

Thesis Reader: Neil E. Todreas
Title: Professor of Nuclear Engineering

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Chapter 1 -- Introduction

1.1 General

Emergency diesel generators (EDGs) perform an essential safety function in every nuclear power plant in the United States. As the centerpiece of the emergency power system, they provide a redundant source of electricity to vital safety equipment in the event of a loss of offsite power.

The failure of a generator to start and run could have far-reaching effects; in extreme cases, core damage or even the loss of human life. In order to ensure that the generators and their support systems are capable of performing their safety function, diesel operators subject the EDGs to numerous mandatory tests and inspections. The United States Nuclear Regulatory Commission (NRC) established these surveillances in order to ensure that the generators have sufficient reliability to maintain the risk of core damage at an acceptable low value.

A recent study performed by the Idaho National Engineering and Environmental Laboratory (INEEL) [1] considered the EDG power system reliability at length. This study indicated that a particular EDG inspection performed during the refueling outage was most likely degrading the reliability of diesels utilized by nuclear utilities. That EDG inspection is the focus of this report.

This report presents an alternative EDG inspection that replaces the current detrimental inspection. Improved reliability of the EDG, improved plant safety and enhanced plant risk are all benefits of adoption of the new inspection.

1.2 Background

In recent years, the United States Nuclear Regulatory Commission (NRC) and the nuclear utilities have recognized that the continual improvement of probabilistic risk assessment (PRA) methodology has justified an increase in its use as a regulatory tool. The NRC now encourages the application of PRA and associated analyses in order to reduce unnecessary conservatism associated with regulatory guides, requirements and license commitments.

The NRC now encourages a risk-informed approach to decision-making where utilities propose regulation based on underlying engineering principles and an assessment of the impact of proposed changes on the plant design. Risk insights and assessments of the change in plant risk then complement this assessment. The NRC terms this process risk-informed, performance-based regulation (RIPBR).

The RIPBR application process is a three-step process initially requiring a detailed description of the change and its rationale. The second step requires an extensive two-part engineering evaluation of the change. The engineering evaluation begins with a traditional deterministic evaluation that proves that the utility satisfies current regulations and meets requirements for conservatism and defense in depth. The second part of the engineering evaluation requires the utility to perform a probabilistic risk evaluation of the change. The results of this evaluation must show that the proposed change is beneficial to plant risk or negligibly detrimental. Once the utility completes the engineering evaluation, it must formulate a plan for monitoring the implementation of the change and ensure that the associated performance goals will be still be met [2].

The NRC is currently working with several volunteer utility companies on various RIPBR pilot projects. These projects include modification of technical specifications, alteration of allowed equipment outage times, in-service inspections and graded quality assurance. These pilot projects should reveal if the NRC move towards utilization of RIPBR enhances the operational safety of nuclear power plants. RIPBR is the basic strategy used throughout this work to analyze the EDG inspection alteration at our cooperating project utility, Millstone Unit 3 (MP-3).

1.3 Thesis Objective and Method of Investigation

Develop an improved refueling outage inspection for emergency diesel generators through application of risk-informed, performance-based regulation methodology.

The first step in the development of the strategy for diesel generator performance improvement was to gain a comprehensive understanding of EDGs and their use. We performed an extensive study of the history, manufacturer, hardware, and operation of the EDGs at Millstone 3. We used this information, along with expert judgment provided by the engineers at Millstone 3, to alter the EDG refueling outage inspection. This alteration included the elimination or periodicity extension of several items with the overall outcome being a shortened, more efficient inspection that is less intrusive to the diesel and reduces the opportunity for human-induced failures.

Professional insight and nuclear EDG history were not the only influences on the final streamlined inspection. This report also relied upon the expertise of non-nuclear industry uses of emergency diesel generators. Chapter 5 presents the expert input provided by the Federal Aviation Administration, the United States Navy, and civilian hospitals.

Jeffrey Dulik, another participant in this study, also influenced the final form of the inspection. He researched monitoring and sensing equipment that could replace or possibly enhance specific inspection items [3].

Once the final form of the inspection is established, there are two possibilities for the application of the new inspection. The first option is to continue to perform the inspection during the refueling outage. Chapter 6 presents this option and the associated risk benefits of the strategy. A shortened inspection has a measurable impact on the critical path of the power plant during its outage. We measure this impact in terms of the hours required to perform it. We present the associated economic benefits later in this report. A shortened inspection also reduces the probability of fuel damage during the refueling outage. Chapter 6 discusses this impact at length.

The second option is to perform the remaining inspection while the plant is operating at power. Chapter 7 shows that this change would reduce the refueling outage critical path duration and the probability of fuel damage during the refueling outage. This change increases the core damage frequency while the plant is operating and the inspection is being performed. However, the resulting rise in risk is negligibly small according to standards set by the NRC and Electrical Power Research Institute (EPRI) [2, 4].

Chapter 8 contains a discussion of the resulting economic and safety benefits of the proposed changes. The final results of this study demonstrate the significant safety as well as economic benefits of the altered inspection.

1.4 Terminology

This report utilizes terminology that is standard within the nuclear industry whenever possible. The following defined terms provide additional clarity:

- <u>Allowed Outage Time (AOT)</u> -- The maximum allowed time out of service for equipment while the plant is operating at power. The value of this requirement is set by the NRC and is different for each plant.
- <u>Critical Path</u> -- For a refueling outage, the sequence of operations that must be performed serially; these critical equipment outages prevent the plant from returning to an operational full power status.
- <u>Defense in Depth (DID)</u> -- The principle of requiring redundancy in equipment and procedures, so that failure of a single component or procedural step does not cause an undesired consequence.
- <u>Infant Mortality</u> -- A period of high equipment failure rate following the introduction of the equipment into service.

- Probabilistic Risk Assessment (PRA) -- A systematic method for transforming knowledge of basic events in a plant and their occurrence frequencies into corresponding integrated system risk profiles.
- Risk-informed, performance-based regulation (RIPBR) -- An approach to decision-making based on an assessment of the engineering impact of proposed nuclear power plant equipment and procedural changes and their associated impact on plant risk.
- Surveillance - A planned maintenance or test performed to meet either regulatory requirements or performed voluntarily for investment protection of the plant.

Chapter 2 -- Literature Search

2.1 General

This section summarizes the literature search performed on the historical path of PRA that eventually led to the research performed in this work. This search is divided into two parts: documents dealing with PRA history and its application, and documents dealing with EDG performance and improvement.

2.2 PRA

WASH-1400 [5], the reactor safety study completed in 1974, is the definitive document upon which all nuclear PRA work has been subsequently based. Sponsored by the United States Atomic Energy Commission, WASH-1400 is the initial (extensive) risk assessment of nuclear power plants that outlines a series of seven tasks (see Figure 2.1). Performance of these tasks revealed that the predominant risk in a nuclear power plant is that of a radioactive fission product release. The report identified the reactor cooling system as the subsystem whose failure initiates this risk making the cooling system the critical portion of the plant.

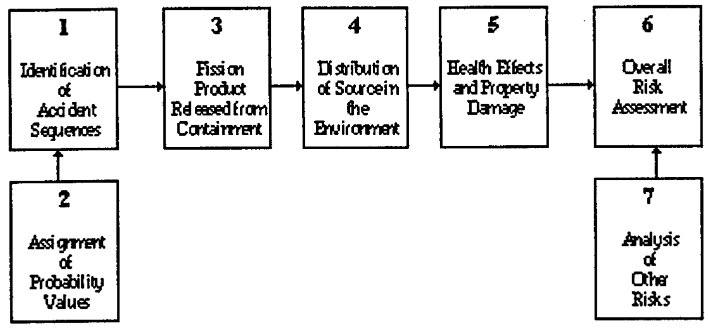

Figure 2.1 WASH-1400 Seven Task Assessment [6]

Although the technical results of WASH-1400 were not fully accepted by nuclear industry professionals and government officials at the time of its release, this document is important because it established the systematic method for transforming initiating events into risk profiles that we today term PRA. Many non-nuclear industries have watched the evolution of nuclear PRA with interest because most aspects of nuclear PRA, with suitable alterations, apply to other fields.

The latest format of nuclear PRA studies consists of a five step process as outlined in the NRC document NUREG-1150. These steps, outlined in Figure 2.2, are very similar to the original seven tasks in WASH-1400.

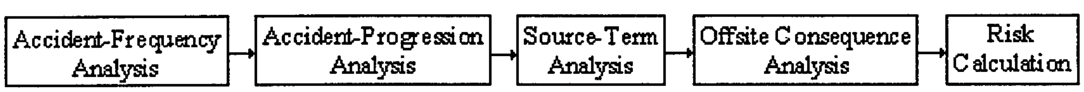

Figure 2.2 Schematic Diagram of Modern PRA Calculational Sequence [6]

New advancements and sophisticated models have prompted the NRC increasingly to adopt PRA technology as a tool in regulatory decision making. The NRC recently issued the 1995 Probabilistic Risk Assessment Policy Statement [7] which along with the PRA Implementation Plan [8] is intended to add PRA to the set of tools used by the agency. The NRC now requires that a plant-specific PRA be submitted by each power plant licensee. This PRA fulfills the plants' obligations under the Individual Plant Examination and the Individual Plant Examinats-External Events programs. These reports are currently being evaluated by the NRC staff in order to identify individual plant risk vulnerabilities.

Leading this move towards increased utilization of PRA is the NRC Chairman, Dr. Shirley A. Jackson. She also has endorsed the use of RIPBR, and in 1996, she subsequently directed the NRC staff to reconstruct its Standard Review Plan and to issue corresponding Regulatory Guides for the aid of licensees attempting to incorporate RIPBR into their PRA analysis. The result of this directive was the November 1996 issuance of DG-1061, an NRC draft regulatory guide promoting the use of PRA for making plant-specific, risk-informed permanent current licensing basis (CLB) changes [9].

In February of 1997, the NRC issued an additional draft regulatory guide that describes an acceptable approach for applying risk-informed methods to Technical Specifications. This guide, DG-1605 (Revision 5), specifically addresses changes to plant allowed outage times (AOTs) and surveillance test intervals (STI) [10]. Also delivered in February were the RIPBR Standard Review Plan revisions [11].

2.3 Emergency Diesel Generator

Despite the long history of EDG use in nuclear power plants, the nuclear industry produced no significant reports concerning the reliability and performance of nuclear diesels until the 1980s. NUREG/CR-2989, *Reliability of Emergency AC Power Systems at Nuclear Power Plants* [12], was the first major report to address the reliability of EDGs. This report addressed the reliability of the on-site ac power system as it relates to the expected frequency of station blackout. In 1986, the Nuclear Science Advisory Committee produced a report entitled *The Reliability of Emergency Diesel Generators at US Nuclear Power Plants* [13] which also addressed the reliability of EDGs although its evaluation methods conflicted with those used in NUREG/CR-2989. In the late 1980s, the Electric Power Research Institute produced a report on EDGs that specifically addressed monitoring and diagnostic techniques that could improve nuclear EDG reliability [14].

As the use of PRA began to expand in the early 1990s, the NRC Office for Analysis and Evaluation of Operational Data (AEOD) undertook an effort to ensure that expanded PRA use could be implemented in a consistent and predictable manner. To achieve this goal, AEOD initiated a review of the functional reliability of risk-important systems in nuclear power plants. One system chosen for performance evaluation was the EDG power system. This evaluation resulted in INEL-95/0035, *Emergency Diesel Generator Power System Reliability, 1987-1993*, which was produced by Idaho National Engineering and Environmental Laboratory (INEL) [1]. This study looked at the reliability of EDGs in 44 plants using actual operating experience under conditions similar to those experienced during an actual loss of offsite power.

2.4 Conclusion

Although the NRC rejected WASH-1400 in 1974, the conclusion that the reactor cooling system was the largest risk contributor to fission product release was not incorrect. In fact, the cooling system is still the largest risk contributor in most plants today. Since EDGs are responsible for powering the cooling system and all other safety systems in case of a loss of offsite power, they themselves are a large contributor to risk. With the increased use of PRA, it is not surprising that INEL was asked to look at EDG reliability in depth.

The INEL report, along with recent NRC PRA documents, form the basis for a project entitled *Integrated Models, Data Bases and Practices Needed for Performance-Based Safety Regulation*. Part of this project involves the application of PRA to specific EDG reliability issues identified by the INEL report. One such issue identified by the authors of the INEL document was the intrusive inspection performed on the EDG during the refueling outage.

The work in this report looks at the EDG refueling outage inspection in depth and proposes changes through the application of PRA as a result of the author's involvement with the project on *Integrate Models, Data Bases and Practices Needed for Performance-Based Safety Regulation.*

Chapter 3 -- The Millstone 3 EDG System

3.1 Introduction

In order to propose steps for reliability improvement of the diesel, we must first present a complete illustration of current EDG requirements and performance issues. The current EDG inspection requirements are necessarily complex and rigorous in order to ensure that nuclear safety goals are met. However, this complexity has in some instances resulted in inspection processes that have structural weaknesses and inspection requirements that produce no apparent benefit [15]. In some cases, these inspection requirements result in a degradation of the reliability and performance of the diesel.

3.2 General Description

The Millstone 3 (MP-3) plant utilizes a typical emergency power supply design that consists of two independent emergency power supply trains connected to separate emergency diesel generators. Most safety systems employ a similar redundant combination in order to safeguard against failure of single component systems. Table 3.1 summarizes the vital parameters of the two identical EDGs utilized at MP-3. Each of the

Manufacturer	Colt-Pielstick
Number of Cylinders	14
Operating Cycle	4-stroke
Rating	4.16 kV 3 phase 60 Hz
Capacity	4,986 kW (continuous) 5,335 kW (2000 hour)

Table 3.1 MP-3 Emergency Diesel Generator Parameters

EDGs is capable of starting automatically and accelerating to rated speed and subsequent loading of all safety and essential shutdown loads within a minimum time interval (for MP-3, this time interval is eleven seconds). In the case of an emergency power demand, one operable EDG is sufficient to handle all safety loads [16].

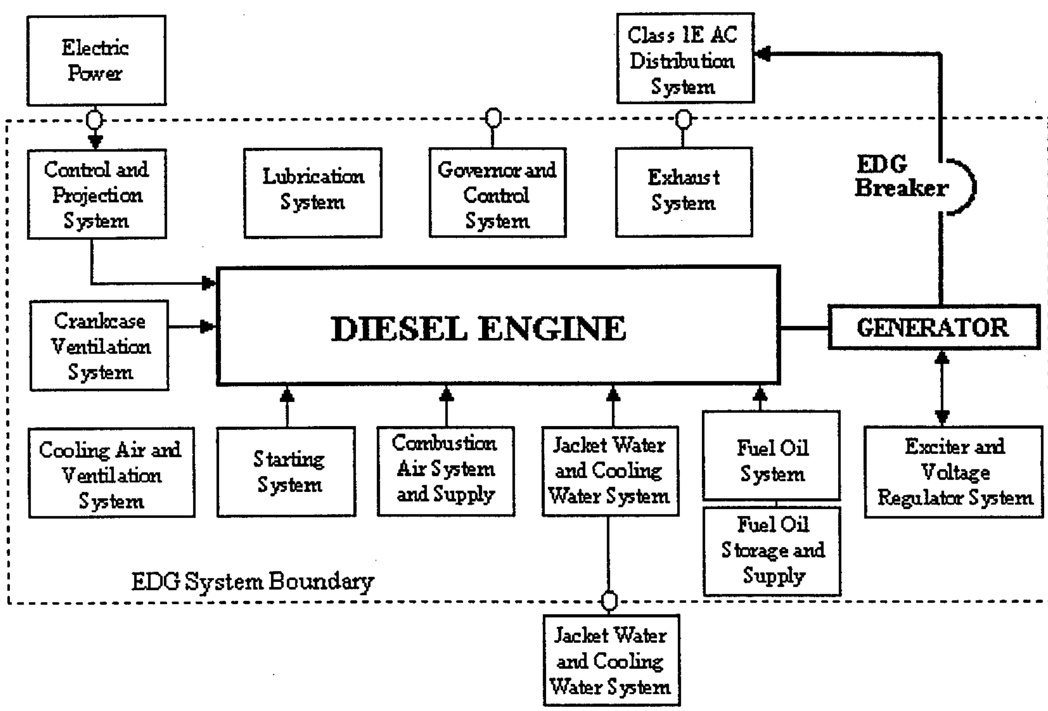

Figure 3.1 Emergency Diesel Generator System

Each EDG has independent support systems to further utilize redundancy and minimize the occurrence of common cause failures. A schematic of one of the EDGs and its many subsystems is illustrated in Figure 3.1. The dashed line represents the boundary of the system and demonstrates that most of the support systems are internal to the EDG system.

3.3 Testing and Inspection Requirements

The primary function of the diesels at MP-3 is to supply power to the plant safety systems in the event of a loss of offsite power. These safety systems are vital loads needed to maintain the plant at a safe condition until offsite sources restore power to the utility. The NRC requires MP-3 to periodically test the generators and related support systems to ensure that the EDGs can perform this vital safety role. These tests primarily consist of periodic time-based runs of the diesel that demonstrate the ability of the generator to fulfill its designed load and response criteria. These tests also provide a means to track and demonstrate the reliability of the EDG to ensure that it has a small effect on the core damage frequency (CDF) of the plant.

In addition to the periodic test runs, the NRC also requires specific maintenance to be performed on each EDG. Each maintenance requirement routinely includes some sort of inspection, visual or otherwise, to be performed in conjunction with the periodic maintenance. These numerous tests, maintenance plans, and inspections are outlined by the NRC in the Technical Specifications(TS) of MP-3 [17], a pertinent excerpt of which can be found in Appendix A.

3.3.1 MP-3 Technical Specification 4.8.1.1.2.g.1

This project deals specifically with Technical Specification 4.8.1.1.2.g.1 which requires that each diesel be subjected to an inspection recommended by the manufacturer of the EDG. MP-3 must perform this inspection on each of its diesels during the plant's refueling outage. This corresponds to inspection frequency of once every 18 months. Appendix B contains the Colt-Pielstick maintenance instructions for standby diesels that form the basis for all diesel maintenance performed at MP-3 [17]. Table 3.2 contains the section dealing specifically with the refueling outage inspection (ROI) [16].

2. Remove and check injection nozzles for operation and opening pressure.
3. Remove, disassemble, clean and repair all air start valves and air start distributors. Clean/replace air start distributor filter.
4. Drain and refill governor and turbochargers with approved oil.
5. Drain, flush and refill outboard bearing with approved oil.
6. Check tightness on all foundation, block to base, oil and water line bolts.
7. Check sample of rocker lube oil for condition and contaminants.
8. Check turbocharger inlet casing and turbo casing water passages for scale. The inside surface of these casings is the best indication for adequacy of water treatment.
9. Check for tightness of exhaust manifold flange bolts to cylinder head (165-195 ft.lbs.).
10. Check all safety and shutdown controls for appropriate pressures and temperatures.
11. Borescope all cylinder liners.
12. Inspect the crankcase end of all cylinder liners.
13. Check main bearing cap tightness and side bolts. Alternately confirm cap tightness to frame and saddle to .0015 feeler gauge.
14. Visually examine gear train and drives, cam shafts and bearings, push rods and rocker arms.
15. Check crankshaft alignment and bearing clearances.
16. Check connecting rod bearing clearances with feeler gauges.
17. Inspect all ledges and corners in crankcase for debris which could indicate other mechanical problems. Confirm all cotters, safety wire and lock tabs are in place and tight.
19. Check alternator coils and poles for indication of movement (visual).
20. Drain and refill alternator bearing lube sump. If oil has contaminates, pull bearing cap and inspect journal.
21. Inspect and clean (if required) overspeed trip mechanism. Check operation according to overspeed trip test instructions.

Table 3.2 Colt-Pielstick Annual/Refuel Inspection Items

Millstone 3 has written two plant-specific maintenance procedure guides based on the recommendations of Colt-Pielstick. The first guide, *Production Maintenance Diesel Generator Mechanical Maintenance (MP 3720CB)* [18], is a general maintenance guide that contains weekly, monthly, annual, and refueling outage inspection and maintenance items. The second document, *Emergency Diesel Generator Surveillance Inspection (SP 3712K)* [19], is a detailed disassembly inspection guideline and checklist for the ROI. Although these two guidelines both contain specific refueling outage inspection items, they remain separated because of the different emphasis of the documents.

Both of these documents contain inspection and maintenance items that are not required by Colt-Pielstick but were determined by MP-3 to be beneficial to the individual EDGs. For this reason, this project will focus only on the items listed in Table 3.2 as these are items required of MP-3 regardless of the benefit or detriment which these items may have on the diesels.

3.4 Conduct of Inspection

MP-3 performs extensive detailed planning prior to each refueling outage at the utility. The diesels are an integral part of the outage plan and must be taken out of service in such a way as to minimize their impact on the critical path of the plant yet at the same time ensure that an appropriate amount of defense in depth is maintained. The last planned refueling outage that took place at MP-3 began in April of 1995. We present the 1995 outage in order to illustrate the planning and execution of the ROI at MP-3.

3.4.1 Electrical Power Supply Outage Schedule

Figure 3.2 is a reproduction of the planned electrical power supply outage strategy utilized by MP-3 to carry out required maintenance and testing of all electrical systems. This outage schedule is in the form of a time bar chart which is a typical format for outage planning utilized throughout the nuclear industry. At the top of the chart, the months of April and May are broken up into weeks so that the approximate starting day and time of each outage can be quickly determined. A time bar indicating the length of each shutdown in hours represents each scheduled equipment outage. The " D = __" symbol gives the approximate time that MP-3 expects each item to be out of service (OOS). Exact start dates and times of the outages are indicated to the left of each bar while the ending dates and times are indicated to the right of each bar.

The far right hand side of the chart gives a brief description of the equipment that is unavailable during each time period. The three main equipment categories that the electrical power supply outage schedule cover are electrical buses, transmission systems, and the EDGs. There are three transformers that appear in this schedule. They include the normal station transformer (NSST), the 'A' reserve station transformer (A RSST) and

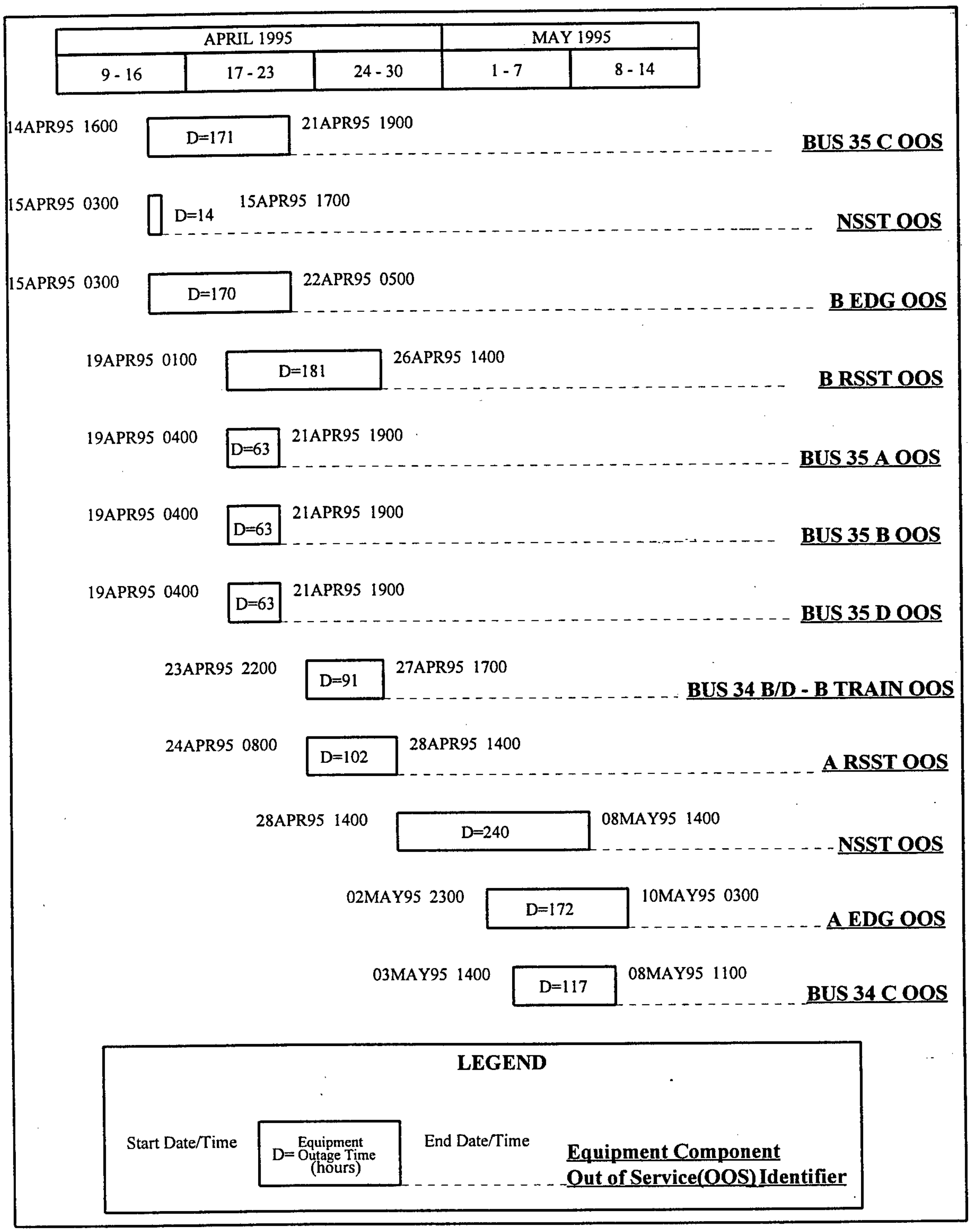

Figure 3.2 MP-3 1995 Electrical Power Supply Maintenance Activities Within the Refueling Outage Schedule [20]

the ‘B’ reserve station transformer (B RSST). The NSST is the normal source of offsite power at the plant while the ‘A’ and ‘B’ RSSTs provide a backup source of power in the event that the normal power transformer is unavailable.

The electrical power supply outage schedule includes numerous bus outages. However, only two of the bus outages affect the ability of the EDGs to supply power in the case of a loss of offsite power. The two buses in question are bus 34 B/D and bus 34 C. We address the impact of these two buses on the EDGs later in this report.

The outage schedule shows that MP-3 scheduled each EDG outage in 1995 for approximately 170 hours, or approximately seven days. EDG outages must not overlap since one diesel must be available at all times in case of a loss of offsite power. This results in a total diesel outage time of 340 hours. Numerous EDG tests occur during this outage time but the bulk of the time is taken up with the ROI. MP-3 allocates approximately 120 of the 170 hours of each outage to the ROI for a total outage time due to both ROIs of 240 to 250 hours.

The MP-3 diesel maintenance engineer utilizes the chart in Figure 3.2 as a general guideline for the conduct of the EDG outage. In addition to this, he uses a much more complex bar chart that details the allotted time for each test and individual inspection item. The MP-3 diesel maintenance engineer uses both of these plans as guidance throughout the refueling outage but is also required to produce real time or “as built” bar charts that detail the actual timeline for each inspection item and the overall conduct of the diesel outage.

3.4.2 Inspection Team Makeup

The MP-3 diesel maintenance engineer conducts the actual ROI with the aid of four to five workers at any one time. Typically, two of these workers are the regular diesel operators while the remaining laborers are general mechanics temporarily brought in from other parts of the plant. These workers usually operate continuously in two shifts so that there are a total of eight to ten workers carrying out the inspection and maintenance [21].

In addition to the MP-3 employees, a Colt factory representative must be present throughout the entire ROI. The Colt representative is responsible for evaluating the condition of the engine and ensuring that all MP-3 workers perform all inspection items. They are additionally responsible for reviewing all Colt Service Information Letters [22] with the maintenance engineer. These letters detail problems that have occurred in similar Colt diesels since their manufacture and provide strategies for preventing similar occurrences in MP-3 diesels.

3.5 The ROI Dilemma

The current EDG refueling outage inspection has frustrated diesel operators and engineers for several years. In regulatory documents, the ROI is termed an "inspection" and at worse, a "disassembly inspection." In practice, however, those tasked with carrying out the inspection refer to it more aptly as a teardown. It is a time-consuming, intrusive process that leaves the diesel vulnerable to human error and exposes the plant to unnecessary safety degradation [15, 20].

The root of the problem is simple: the diesels used at nuclear power plants to provide backup power were not designed for that use. Manufacturers designed these diesels mainly for marine operation in which they operate for extended periods of time with heavy loads. Overhauls of these diesels typically occur after logging hours in the thousands to tens of thousands range. The operators of these diesels perform overhauls to identify worn and degraded parts resulting from extended operation. Nuclear utilities, by contrast, usually perform diesel overhauls after only approximately one hundred hours of use.

It is easy to understand why this has happened. When MP-3 and the NRC established the Technical Specifications, the authors most likely acknowledged that the EDGs would not log the hours typically required for a major overhaul. However, both parties considered overhauls a necessary part of a comprehensive maintenance program. Instead of requiring a minimum number of hours of operation before overhaul, a time constraint was chosen by the TS authors as a convenient alternative. This move is similar to an automobile warrantee -- 3 years or 30,000 miles. In order to make the overhaul of the diesel compatible with the operating cycle of the power plant, the overhaul frequency was matched to the refueling cycle. MP-3 most likely adopted this policy based on the belief that the plant was less vulnerable to reactor fuel damage during the refueling period and therefore the need for an EDG was reduced [15].

The utilities established the overhaul requirements at a time when the plants had little operational history. Today's on-line monitoring systems and techniques were not available to diesel operators. Regulators established strict deterministic guidelines with a great deal of built-in conservatism and inflexibility. However, today's more systematic, performance-oriented regulatory climate has prompted evaluation of the current regulations, which, in the case of the EDG, have been found to be lacking.

The authors of the INEL report on EDG reliability felt that there was a general trend of over-testing and over-inspecting the diesel which the operational history of the EDGs did not warrant [15]. The overhaul inspections were not finding the wear and tear on diesel parts that the regulators designed them to find. Instead, they found that these inspections were an avenue in which human errors might induce immediate or latent failures. Other failures may be introduced through non-human means such as the warpage of parts upon removal. The immediate failures, which contribute to the infant mortality rate of the EDG, were not well documented by diesel operators but rather were related to the authors through numerous anecdotes. Experts explained the reason for this lack of documentation as a result of a grace period that the utility gives to the diesel operators at the completion of the ROI. This policy allows operators to run the diesel to ensure its operability before the commencement of recorded testing. The diesel operators and the NRC do not consider failures that occur during the trial run to be recordable [21].

An additional concern addressed in the INEEL report was the omission of maintenance out of service (MOOS) demands as failures when determining a plant's ability to meet its EDG safety goals. A MOOS failure occurs when there is a real demand on the diesel during a loss of offsite power event and the diesel is unavailable to operate because it is being inspected or having maintenance performed. In order to avoid the danger that this situation implies, utilities have traditionally performed the overhaul during plant shutdowns. However, it has become widely recognized that the times of greatest plant risk may not be those when the plant is operating at high power. Rather, when a plant is undergoing refueling, its vulnerability for reactor fuel damage due to fuel cooling failures may be considerably greater than when at high power. This is because of the greater complexity of plant configuration control -- with an attendant increase in human error probabilities, and because of reduced redundancy in accomplishing the fuel cooling functions. The requirements for EDG intrusive inspections exacerbate the possibilities of such cooling failures during refueling outages and may actually increase plant fuel damage risks. Reduced inspection requirements would reduce this concern [1, 15].

There are structural problems with the ROI as well. The required presence of the Colt representative results in a difficult dilemma for the EDG system team at MP-3. The NRC requires only that MP-3 carry out those inspection items deemed necessary by the manufacturer. Document SP 3712K outlines the inspection stating specifically that "Inspection items may be altered or deleted if sufficient justification warrants the change as judged by the Colt representative and the MP-3 maintenance engineer [19]." According to the MP-3 maintenance engineer, this rarely happens in practice. If any part of the inspection is eliminated or shortened by MP-3, this in turn shortens the time that the Colt-Pielstick representative is needed as a consultant at MP-3. A termination of inspection items might also result in a smaller demand for Colt-Pielstick manufactured replacement parts. These reasons provide a possible explanation for the impasse in adjusting the set of required inspections experienced in MP-3 and other plants [21].

In summary, consensus exists among those persons who operate, inspect and evaluate the EDG that the utilities, with the cooperation of the NRC, need to improve or even eliminate the current overhaul requirements. They cause far too frequent invasion of the equipment which often results in failures caused by human error. The outage time associated with the ROI is significant and unnecessarily increases the probability of damage to the reactor fuel due to the EDG being unavailable for service. The ROI was established at a time when there was no operational history. However, today's experience and insight demonstrate the diesel ROI can and should change accordingly.

Chapter 4 -- ROI Improvement Proposal Based on Nuclear Industry Expert Opinion

4.1 Introduction

The present ROI contains both structural and operational problems that can benefit from change. In order to develop an improved ROI, we used the expert opinion of the diesel engineer at MP-3 to assess each inspection item. The compilation of his suggestions and recommendations result in a streamlined version of the original ROI. The abbreviated inspection emphasizes non-intrusive practices, engine analysis, and improved human oversight.

4.2 Structural Change

The first step in the improvement of the performance of the diesel involves removal of barriers that currently inhibit change. Currently, the main barrier to alteration of the ROI is the power which TS 4.8.1.1.2.g.1 affords the manufacturer of the EDG. No change can take place in the ROI unless the manufacturer, whom MP-3 pays to oversee the ROI, approves of the alteration. This results in an obvious conflict of interest.

Alteration of this fundamental structural problem can only take place through a change in the Technical Specification. This report justifies inspection alteration through the presentation of the numerous risk and safety benefits that an altered ROI will produce. A formulation of an alternative structure for the administration of this TS is not the focus of this work. However, we discuss possible options in Chapter 10 as a starting point for future work in this area.

4.3 ROI Assessment

Identification of those parts of the ROI that do not benefit the EDG at MP-3 is a crucial step in the alteration of the inspection. We accomplished this identification process through a series of interviews with the MP-3 diesel maintenance engineer [21]. The maintenance engineer has an extensive knowledge of the engine past performance history as he has been responsible for the diesel maintenance since the plant start up. He has conducted EDG inspections through five refueling outages and is currently involved with proposing changes to the ROI in conjunction with the EDG owner's group.

The diesel engineer carefully reviewed each of the twenty inspection items before issuing an opinion on the best way to improve the individual requirements. In order to determine the best option for each requirement, the diesel engineer answered the following questions:

1) What is the purpose of this item?
2) Does this requirement accomplish its purpose?
3) Is the requirement excessively intrusive to the diesel?
4) Could this item be eliminated?
5) Could this inspection item be improved or replaced with the aid of monitoring?
6) Could this inspection item benefit from periodicity extension?

Each of these questions hits on a key aspect for improvement of the performance of the diesel.

4.3.1 Individual Requirement Purpose

The first two questions concerning the purpose of each requirement ascertain the fundamental goal of each inspection item. If an inspection item is not accomplishing its purpose, there is no reason to continue carrying out the item. Unnecessary items are time consuming and provide needless avenues for human error introduction. Additionally, if the item does not accomplish its purpose, this may mean that the inspectors should adopt an alternative inspection method.

4.3.2 Excessive Intrusiveness

The question of "excessive intrusiveness" is a vital assessment that addresses the potential detriment of individual inspection items. Intrusiveness is a broad term that expresses the level of entry into the diesel required by a particular inspection. Diesel experts consider inspection items intrusive if they require disassembly of several parts of the diesel. A determination of excessive intrusiveness requires the diesel engineer to weigh the potential benefits and detriments of each item. If the benefits realized by the performance of an inspection do not outweigh the potential downsides, then the diesel engineer considers the requirement excessively intrusive. We considered inspection items automatic candidates for alteration if the diesel engineer determined the items to be excessively intrusive.

Reduction of intrusiveness benefits the hardware of the diesel in several ways. Every time a diesel worker disassembles a part of the diesel, the EDG is potentially exposed to warpage and the introduction of moisture. Both of these phenomena can cause degradation of the diesel performance and in some cases, failure. Intrusiveness additionally exposes the diesel to the introduction of errors caused by human action. The diesel inspectors can improperly disassemble or reassemble the EDG. Tools, clothing, or loose diesel parts can fall inside of the diesel. Additionally, diesel operators may misplace parts during disassembly which can potentially delay completion of the inspection.

4.3.3 Item Elimination

Some inspection items may qualify for total elimination if the diesel engineer considers the initial purpose of the requirement unnecessary. A determination of total elimination requires the diesel engineer to assess the benefits of the inspection and to determine if the information gained by the inspection is valuable or gives unique information about the status of the diesel. Unnecessary inspection items consume time and resources and provide an additional avenue for the introduction of human error. Total elimination can apply to both intrusive and non-intrusive items.

4.3.4 Monitoring As An Alternative

Engine analysis and monitoring can replace or enhance current inspection requirements. The EDGs at MP-3 utilize a newly installed engine analysis system called RECIPTRAP. This system provides a copious amount of information to the operators of the diesel and has proved quite valuable since its installation. The MP-3 diesel engineer stated that the information provided by this system could adequately replace several of the current inspection items. The diesel engineer also suggested use of additional monitoring devices not currently in place at MP-3 that could adequately replace current inspection items [21].

4.3.5 Periodicity Extension

The final question posed to the diesel engineer was that of the periodicity extension of individual items. Periodicity extension refers to the lengthening of the current eighteen month time-base of the ROI for specific requirements. This would apply to items that the diesel engineer feels are necessary for the safe operation of the diesel but the inspection requires too frequently. The diesel engineer often recommended periodicity extension in conjunction with engine analysis.

4.4 ROI Recommendations

Tables 4.1 - 4.3 display the diesel engineer's expert opinion and assessment of each inspection item. Each table represents one of three categories of alteration that MP-3 should make on the individual inspection items. The first table lists those inspection items that provide net benefits to the diesel in their present manner. The diesel engineer recommended that no changes be made to these items. Table 4.2 contains those inspection items that the diesel engineer feels will benefit from periodicity extension.

The final table, Table 4.3, contains inspection requirements that the engineer feels will benefit from replacement with monitoring or sensing equipment.

Each of the three tables is organized in an identical manner. The first column lists the inspection items currently required by Colt-Pielstick. There are two item numbers missing from the table. The numbering of the items begins at number two because item one refers to performance of regular maintenance required of the diesel operators and is not an actual inspection item. Item 18 is missing from the table because the manufacturer no longer requires this item and current literature does not contain the updated numbering system. Item three is in both Tables 4.2 and 4.3 as the engineer felt that it could benefit from the installation of sensing equipment as well as periodicity extension.

The second column of each table contains a brief description or commentary on the inspection requirement. In some cases, this commentary describes the inspection process if it is unusual or unclear. In other cases, the commentary sets forth the objective of a particular inspection item.

The final column contains the recommendations of the diesel engineer. After careful consideration of the six questions outlined in Section 4.3, he delivered a commentary that outlines problems with the current inspection. This column contains the engineer's proposed solution to improve the inspection item.

The diesel engineer recommended that eleven of the nineteen inspection items remain unaltered (Table 4.1). The MP-3 engineer noted that inspection of the crankcase end of all cylinder liners (Item 12) is an item that provides limited knowledge to the inspectors. He did not recommend the item for alteration, however, because of the limited resources of time and personnel required to perform the inspection. The diesel engineer identified two items of the nineteen assessed as intrusive inspections that MP-3 should not alter in any manner. The first such example is Item 13 which requires checking the main bearing cap tightness. Despite the intrusive nature of this inspection, it is vital to ensure that caps are kept tight in order to avoid bearing damage. The second inspection is Item 21 which requires a static test of the overspeed trip mechanism. Although the static test is intrusive, it has no adequate replacement and should continue as part of the ROI in its original form.

Item # From Current ROI Checklist	Current Colt-Pielstick Requirement	Description	MP-3 Diesel Engineer Recommendations
5	Drain, flush and refill outboard bearing with approved oil.	The outboard bearing is subjected to oil replacement to ensure a high quality and appropriate level of oil is present within the equipment.	No change recommended.
6	Check tightness on all foundation, block to base, oil and water line bolts.	Bolt checking tasks involve verifying that they are wrench tight. Properly tightened bolts prevent leakage and insure the integrity of the diesel.	No change recommended.
7	Check sample of rocker lube oil for condition and contaminants.	A comprehensive assessment of oil quality can identify numerous problems within the EDG including water leaks and corrosion.	No change recommended.
8	Check turbocharger inlet casing and turbo casing water passages for scale. The inside surface of these casings is the best indication for adequacy of water treatment.	Proper water treatment is essential because it protects the hardware of the diesel from corrosion.	No change recommended.
10	Check all safety and shutdown controls for appropriate pressures and temperatures.	Safety systems on the diesel guarantee that the EDG will shut down if it is operating in a dangerous condition.	No change recommended.
12	Inspect the crankcase end of all cylinder liners.	This inspection is performed to identify debris that has entered this space.	This inspection is not intrusive but has limited usefulness.
13	Check main bearing cap tightness (9950-1100 psi hydraulic) and side bolts (hammer tight). Alternately confirm cap tightness to frame and saddle to .0015 feeler gauge.	The consequence of loose bolts in this area can be serious. The bolts are checked for proper tightness to prevent bearing damage.	This inspection is intrusive but should be performed.
16	Check connecting rod bearing clearances with feeler gauge.	This check determines the need for bearing replacement and is now performed visually.	No change recommended.
17	Inspect all ledges and corners in crankcase for debris which could indicate other mechanical problems. Confirm all cotters, safety wire and lock tabs are in place.	This visual inspection identifies debris that may cause future problems within the diesel.	No change recommended.
20	Drain and refill alternator bearing lube sump. If oil has contaminants, pull bearing cap and inspect journal.	A comprehensive assessment of oil quality can identify numerous problems within the EDG including water leaks and corrosion.	No change recommended.
21	Inspect and clean (if required) overspeed trip mechanism. Check operation according to overspeed trip test instructions.	This inspection is a static test that ensures the trip mechanism moves smoothly. This equipment performs an important safety role within the diesel.	This inspection is intrusive but beneficial and should not be altered.

Table 4.1 Refueling Outage Inspection Items Not Recommended for Alteration

Item # From Current ROI Checklist	Current Colt-Pielstick Requirement	Description	MP-3 Diesel Engineer Recommendations
3*	Remove, disassemble, clean and repair all air start valves and air start distributors. Clean/replace air start distributor filter.	Engine starting is accomplished by the action of compressed air on the cylinders in their proper firing order. All valves and distributors must be completely disassembled and cleaned.	Short runs of the EDG tend to leave "gunk" which this inspection reveals. However, problems in this area can be revealed with the aid of temperature sensors on the air supply line. A periodicity extension to once every other refuel would be beneficial.
4	Drain and refill governor and turbochargers with approved oil.	The governor and turbochargers are subject to oil replacement in order to ensure a high quality and appropriate level of oil is present within the equipment. Oil lubrication is an essential part of a comprehensive maintenance plan.	This practice is not intrusive or time consuming but does provide an opportunity for human error. Periodicity extension would be beneficial here.
14	Visually examine gear train and drives, cam shafts and bearings, push rods and rocker arms.	A visual check of these areas allows for the identification of excessive wear or damage.	The bearing check is an intrusive process. The periodicity should be extended to every other refuel.

Table 4.2 Refueling Outage Inspection Items Recommended for Periodicity Extension
(*Item 3 also appears in Table 4.3 as it benefits from both periodicity extension and installation of sensing equipment.)

Table 4.2 lists the three items that the MP-3 diesel engineer identified as benefiting from periodicity extension. These are items where the engineer judges that the current ROI requires being performed too frequently -- to the detriment of the diesel itself. Item three requires the inspector to disassemble and clean all of the air start valves. Although this type of inspection can reveal problems with the valves, engine analysis can also reveal this information without the intrusiveness of disassembly. However, periodic cleaning of the air start valves is still beneficial and the new inspection should require cleaning every other refueling outage as a maintenance procedure.

Item four requires the inspection team to drain and refill the governor and turbocharger oil. Although changing oil is a good maintenance practice, the small number of hours that the diesel operates does not justify changing the oil every refueling outage. The diesel engineer judged that extension of the oil change to once every other refueling outage will not noticeably degrade the oil quality.

Historically, the visual inspection of the camshaft bearings has found scoring on only one occasion. Further investigation has determined that this scoring occurred during the original startup of the diesel. Subsequent inspections have found no problems and the diesel engineer recommended that this inspection be performed only once every other refueling outage.

It is important to note that periodicity extension does not necessarily mean that MP-3 should only perform an individual item every other refueling outage. In some cases, the inspection team can split a task between two refueling outages. For example, the team can inspect half of the air start valves during one refueling outage leaving the other half for inspection during the next ROI. This practice promotes continuity and standardization between subsequent ROIs and allows the operator performing the inspection to be more familiar with the mechanics of disassembly.

MP-3 has implemented several monitoring and trending programs since the diesels were first operated. Monthly lubrication oil analyses, start time trending, and cylinder temperature trending all provide alternate, indirect methods for determining the existance of possible engine problems. The diesel engineer expressed the importance of parallel execution of all of these programs that in many cases provide more information about the status of the diesel than visual or disassembly inspections. Lubrication oil analyses is especially important because it can reveal internal engine water leaks and can even identify excessive parts wear or bearing problems if analysis detects metal particles in the sampled oil.

Table 4.3 summarizes the alterations that the diesel engineer judges are justified with the use of current monitoring and trending programs that are currently available to diesel operators. MP-3 already utilizes several of these programs and the diesel engineer hopes to implement others in the future. Two benefits realized through use of monitoring and sensing equipment are the reduction in the number of intrusive practices and the reduction in the numbers of avenues for human error [21].

Item # From Current ROI Checklist	Current Colt-Pielstick Requirement	Description	MP-3 Diesel Engineer Recommendations
2	Remove and check injection nozzles for operation and opening pressure.	Injection nozzles spray fuel into the cylinder. The nozzles are subjected to a static test which assesses their spray pattern and opening pressure. Failure of the injection nozzle or pump will result in an increased loading on the other pistons to maintain engine power output.	The static test currently performed is not an accurate simulation of actual run conditions. <u>Engine analysis</u> would be more beneficial especially since this is and extremely intrusive practice. Also, there is evidence that the engine is not sensitive to minor failures of the injectors.
3*	Remove, disassemble, clean and repair all air start valves and air start distributors. Clean/replace air start distributor filter.	Engine starting is accomplished by the action of compressed air on the cylinders in their proper firing order. All valves and distributors must be completely disassembled and cleaned.	Short runs of the EDG tend to leave "gunk" which this inspection reveals. However, problems in this area can be revealed with the aid of <u>temperature sensors</u> on the air supply line. A periodicity extension to once every other refuel would be beneficial.
9	Check for tightness of exhaust manifold flange bolts to cylinder head (165-195 ft.lbs).	Proper tightness of bolts insures that significant exhaust leakage does not occur.	This practice is time consuming and could be replaced with <u>exhaust leakage monitoring</u>.
11	Borescope all cylinder liners.	Borescoping of the cylinder liners involves inserting a viewing device into the individual cylinders. The borescope allows the inspector to identify areas of excessive wear.	This practice is unnecessary and extremely intrusive. No problems have been identified in the MP-3 diesels with this method and the liners always look brand new. <u>Engine and oil analysis</u> as well as <u>monitoring</u> of the firing pressure would reveal the problems this test was designed to identify.
15	Check crankshaft alignment and bearing clearances.	This test provides information about bearing condition and alignment of the crankshaft. Proper alignment is essential for operation of the diesel.	Web deflection is very intrusive and difficult to perform. It has never revealed problems at MP-3. <u>Vibration analysis and oil analysis</u> would both reveal any problems.
19	Check alternator coils and poles for indication of movement (visual).	This inspection reveals problems caused by arcing within the diesel.	This inspection is not intrusive to the internals of the diesel but requires a great deal of outer disassembly to access the area. This practice is very time consuming and could be replaced with <u>resistance monitoring</u>.

Table 4.3 Refueling Outage Inspection Items Recommended for Replacement with Engine Analysis, Monitoring, or Sensing Activities (*Item 3 also appears in Table 4.2 as it benefits from both periodicity extension and installation of sensing equipment.)

Monitoring and sensing techniques have some disadvantages and costs. Introduction of new equipment into the system requires retraining of the operators. For example, proper and rigorous training of diesel operators is necessary before MP-3 implements the new equipment. Also, the equipment itself may malfunction and provide incorrect readings. In order to combat malfunctioning sensors, the diesel operators must install multiple apparati in order to provide redundant, and therefore more reliable, readings [3].

4.4.1 ROI Recommendations Summary

The MP-3 diesel engineer is very familiar with the operational history of the two EDGs in question. His recommendations are based on extensive experience and first-hand application of the Colt-Pielstick requirements. The ROI alterations listed in Tables 4.2 and 4.3 drastically reduce the intrusiveness of the current overhaul and place increased reliance on monitoring and sensing equipment.

4.5 Recommendation Comparison

In order to assess the value of the recommendations made by the MP-3 diesel engineer, we solicited additional opinions from sources within the nuclear industry. The first set of opinions comes from the diesel engineer at Millstone 2 (MP-2) [23]. His opinions concerning the individual inspection items closely agree with those made by the MP-3 diesel engineer. We also reviewed a second set of recommendations for ROI changes from the EDG Owners' Group and discovered several similarities with the proposed alterations [24].

4.5.1 MP-2 Diesel Engineer

We obtained an additional expert opinion concerning the Colt-Pielstick ROI from the diesel engineer at MP-2 in an effort to assess the consistency of the recommendations made by the MP-3 engineer. The MP-2 diesel engineer has extensive EDG experience and fills the same position as the MP-3 engineer on the ROI team. We selected him for his expertise and because he oversees the MP-2 diesels in a similar management and operational environment as that of MP-3. Additionally, the diesel operators and laborers utilized during the ROI activities in MP-2 are trained similarly to those working in MP-3.

Although Colt-Pielstick manufactures the diesels utilized in MP-2, the EDGs are opposed piston diesels, which make them fundamentally different from those utilized in MP-3. This structural difference results in a distinct set of ROI requirements that are difficult to compare to the MP-3 requirements. We therefore asked the MP-2 diesel engineer to review the MP-3 requirements and give his opinion on the inspection items based on his general diesel expertise. Using the same six questions as a guide, the MP-2 diesel engineer proposed the recommendations found in Table 4.4.

Item # From Current ROI Checklist	Current Colt-Pielstick Requirement	MP-2 Diesel Engineer Recommendation
2	Remove and check injection nozzles for operation and opening pressure.	One fourth of the injectors usually fail the "pop" test. However, the engine does not appear to be sensitive to these failures. Beta RECIPTRAP vibration readings may be a more beneficial test.
3	Remove, disassemble, clean and repair all air start valves and air start distributors. Clean/replace air start distributor filter.	The periodicity of this inspection should be changed to 36-48 months.
4	Drain and refill governor and turbochargers with approved oil.	The governor oil should be replaced every 36-48 months.
10	Check all safety and shutdown controls for appropriate pressures and temperatures.	Recommend periodicity change to 36 or 48 months.
11	Borescope all cylinder liners.	No change. Beta RECIPTRAP may reveal problems with liners.
15	Check crankshaft alignment and bearing clearances.	Recommend extension of periodicity to 36 months.
19	Check alternator coils and poles for indication of movement (visual).	Opposed piston diesels do not have an access problem but other diesels may experience difficulty.
21	Inspect and clean (if required) overspeed trip mechanism. Check operation according to overspeed trip test instructions.	Periodicity should be extended.

Table 4.4 MP-2 Diesel Engineer Recommendations for EDG Refueling Outage Inspection Changes [Shaded items indicate agreement with recommendations made by the MP-3 diesel engineer]

The MP-2 diesel engineer identified eight inspection items that he judged would benefit from alteration. This number is identical to that identified by the MP-3 diesel engineer. The six shaded items in Table 4.4 are requirements that both of the diesel engineers identified as candidates for alteration. The recommendations for these six items are not exactly the same but have a similar nature. The alterations suggested by the MP-2 engineer consisted mostly of recommendations for periodicity extension. This contrasts with the MP-3's alterations which relied more heavily on engine analysis and monitoring.

The MP-2 diesel engineer was quick to mention that the diesels at MP-2 were not as rigorously monitored as those in MP-3. This may account for the lack of engine analysis replacement in his recommendations. The MP-2 diesel engineer did, however, attempt to note items that he judged could be replaced by engine analysis. For example, he listed the borescoping required by Item 11 as a possible candidate for replacement by engine analysis.

The MP-2 diesel engineer judged that the current Colt-Pielstick requirements subjected the diesels to unnecessary intrusiveness that alteration of the ROI would reduce. He also agreed that the recommendations made by the MP-3 diesel engineer were appropriate for the MP-3 diesels.

4.5.2 Fairbanks Morse Owners' Group

MP-3 is a member of the Fairbanks Morse Owners' Group (FMOG), an organization of utilities that utilize Colt-Pielstick diesels (Fairbanks Morse manufactures Colt-Pielstick diesels). FMOG recently released a set of proposed changes to the ROI requirements [24]. These will soon be presented to Colt-Pielstick for adoption. The recommendations made in this document are confidential at this time but they agree closely with the recommendations made by the MP-3 diesel engineer. This is not surprising as the MP-3 diesel engineer assisted to a limited extent in the preparation of these recommendations.

4.5.3 Summary

Comparison of the recommendations of the MP-2 diesel engineer and the FMOG to the ROI alterations proposed by the MP-3 diesel engineer reveals that all agree that MP-3 should alter its inspection requirements. The MP-2 diesel engineer and the

Owners' Group both recommend a majority of the items recommended for alteration by the MP-3 engineer. This demonstrates that the MP-3 engineer's recommendations are valid alterations which address inspection items that contradict fundamental engineering practices.

The MP-3 diesel engineer's familiarity with the operational history of the MP-3 diesels may account for recommendations for specific item alterations that the MP-2 engineer and FMOG did not recommend. For example, the MP-3 engineer recommended an increase in the periodicity of camshaft bearing inspections that the MP-2 diesel engineer did not suggest. The MP-3 diesel engineer based this recommendation upon the operational history of the EDGs in MP-3 with which the MP-2 diesel engineer is not familiar.

We henceforth treat the MP-3 diesel engineer's ROI alterations as constituting a reference set of recommendations, based upon sound engineering principles that increase the reliability of the diesels.

4.6 Conclusion

The MP-3 diesel engineer has a comprehensive and extensive knowledge of the EDGs at MP-3. His recommendations for the ROI fell into one of three categories: 1) No change, 2)periodicity extension, or 3)engine analysis, monitoring, or sensing replacement. Of the nineteen items currently required by Colt-Pielstick, the MP-3 engineer recommended the alteration of eight of them. Comparison of additional expert opinion recommendations to those made by the MP-3 engineer revealed agreement with his alterations. The ROI resulting from his recommendations is a streamlined inspection set that is much less intrusive into the diesel and relies heavily upon engine analysis, monitoring and sensing for indication of EDG degradation. We utilize the improved refueling outage inspection (IROI), summarized in Table 4.5, throughout this work as a model for diesel reliability improvement.

IROI Item #	IROI Requirement
1	Remove, disassemble, clean and repair half of all air start valves and air start distributors. Clean/replace associated air start distributor filter.
2	Drain and refill governor and turbochargers with approved oil every other refuel.
3	Drain, flush and refill outboard bearing with approved oil.
4	Check tightness on all foundation, block to base, oil and water line bolts.
5	Check sample of rocker lube oil for condition and contaminants.
6	Check turbocharger inlet casing and turbo casing water passages for scale. The inside surface of these casings is the best indication for adequacy of water treatment.
7	Check all safety and shutdown controls for appropriate pressures and temperatures.
8	Inspect the crankcase end of all cylinder liners.
9	Check main bearing cap tightness (9950-1100 psi hydraulic) and side bolts (hammer tight). Alternately confirm cap tightness to frame and saddle to .0015 feeler gauge.
10	Visually examine gear train and drives, cam shafts, push rods and rocker arms. Visually examine camshaft bearing every other refuel.
11	Visually check connecting rod bearing clearances.
12	Inspect all ledges and corners in crankcase for debris which could indicate other mechanical problems. Confirm all cotters, safety wire and lock tabs are in place.
13	Drain and refill alternator bearing lube sump. If oil has contaminants, pull bearing cap and inspect journal.
14	Inspect and clean (if required) overspeed trip mechanism. Check operation according to overspeed trip test instructions.

Table 4.5 Final Set of Improved Refueling Outage Inspection (IROI) Requirements

Chapter 5 -- Non-Nuclear Power Industry EDG Standards and Requirements

5.1 Introduction

The nuclear power industry is not the sole operator of diesel engines for emergency or standby use. Diesels are used for emergency backup power throughout the country in hospitals, laboratories and buildings where elevator use is critical. The Federal Aviation Administration maintains EDGs at its air traffic control centers in order to provide backup power for vital equipment in case of a loss of offsite power. The US Navy uses EDGs onboard nuclear surface ships and submarines in order to provide power to safety systems if the reactor is shut down. All of these applications rely upon the EDG in some way to prevent the loss of human life or property making their reliable operation critical.

Although EDG experts within the nuclear power industry agreed that the ROI requirements are intrusive and performed too frequently, they generally had little knowledge of how these requirements compared to EDG practices outside the nuclear power industry. A survey of experts in the US Navy, the FAA and non-nuclear industries revealed that they generally agreed with the assessment of the nuclear EDG experts. The EDGs in these various industries undergo overhaul rarely, if ever. A line by line comparison of the eighteen month inspection requirements for the nuclear power industry, the FAA, and the US Navy reveals that the nuclear power inspection is much more rigorous and intrusive to the diesel than inspections required by the others.

Despite less-rigorous and intrusive inspections, the other groups using EDGs appear to be quite satisfied with the performance and reliability of their respective diesels. This knowledge, in conjunction with the line-by-line ROI comparison, supports the nuclear power industry expert opinion that the EDGs willl benefit from alteration of the intrusive inpections.

5.2 US Hospitals

A loss of commercial power in a hospital can be disastrous for patients depending upon electrically powered life-sustaining equipment. Emergency diesel generators literally become a lifeline for these people during a power outage. For this reason, the EDGs used in hospitals are governed by numerous safety codes which set forth maintenance and testing requirements designed to keep the diesel operating at a high level of reliability [25].

Maintenance engineers in two Boston area hospitals answered questions concerning the diesels that they supervised [26, 27]. Both engineers have extensive experience with the diesels in their care and are familiar with the operational history of each of the diesels. The EDGs used in these hospitals are manufactured by various vendors and vary greatly in age and load capacity. The operators of these diesels, however, subject all of the diesels to the same testing and maintenance requirements.

Hospital employees perform most of the maintenance and testing on their diesels although each of the hospitals also hires a certified generator maintenance contractor to fulfill periodic additional maintenance needs. The contractor only performs an overhaul on these diesels when testing or routine maintenance reveals a problem. One of the maintenance engineers recalled only one overhaul taking place at his hospital over a period of twenty-two years. That particular diesel needed an overhaul as a result of numerous instances of unloaded operation.

When asked about the source for the diesel testing and maintenance requirements, both engineers stated that they have some freedom to set their own requirements. However, both stated that they understand the minimum standards to which they must adhere are set by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO).

5.2.1 Code Requirements

An investigation of the JCAHO requirements for testing and maintenance of EDGs revealed that this organization is one of three groups that dictate guidelines for safe operation of emergency diesel generators in hospitals. These three groups provide fairly consistent requirements that they encourage but do not require each hospital to adopt.

5.2.1.1 The JCAHO

The JCAHO is a national accreditation organization whose mission is to improve the quality of care provided to the public. Hospitals seek accreditation from this organization in order to prove to the public, insurance companies, and others that it adheres to a set of standards recognized as those belonging to a quality healthcare organization. The JCAHO standards focus mainly on EDG testing and leave maintenance plans to the individual hospital [25].

5.2.1.2 The National Fire Prevention Association

The National Fire Prevention Association (NFPA) is also a voluntary, non-governmental association dedicated to fire safety and related hazards. The NFPA has established two codes that affect the operation of EDGs in hospitals. The first code deals specifically with healthcare facilities while the other is a general standard for emergency and standby power systems. Testing requirements set forth by these codes are very similar to those required by the JCAHO. The NFPA also stresses the importance of development of a preventive maintenance program and publishes a set of comprehensive periodic maintenance items that it recommends for the safe operation of EDGs [28].

5.2.1.3 The National Electrical Code

The final source of requirements for EDGs in hospitals is the National Electrical Code (NEC). The guidelines and testing set forth by the NEC are extremely general and compliance with the JCAHO and NFPA requirements ensure compliance with NEC standards [25].

5.2.2 Code Requirement Compliance

None of the organizations listed in Section 5.2.1 enforce the standards that they propose for safe operation of EDGs. Compliance by the individual hospital is voluntary although some states require accreditation for fulfillment of licensing requirements. Also, a satisfactory accreditation status of a hospital may favorably influence the liability insurance premiums of the hospital [29]. In this respect, hospitals abide by JCAHO standards because of economic motivation. We observe it is also reasonable to assume that hospitals comply with JCAHO and NFPA standards out of a moral obligation to preserve human life.

5.2.3 Hospital EDG Summary

Although EDG testing and maintenance requirements are not as strenuous as those required in nuclear power plants, engineers that oversee the hospital diesels judge that their generators perform at a high level of reliability even though they typically cannot quantify its value. Hospitals rarely, if ever, perform overhauls on their diesels. Although the JCAHO, the NFPA, and the NEC do not rigorously enforce their standards, they do provide a standard guideline for all diesel engineers to adhere to regardless of diesel manufacturer or diesel size. Individual maintenance plans and overhaul schedules are left to the discretion of the diesel engineer charged with the direct oversight of the individual EDGs.

5.3 The Federal Aviation Administration

The Federal Aviation Administration (FAA) is the federal agency charged with oversight of all civilian air travel, both public and private, in the United States. Operating under the Department of Transportation, the FAA's primary mission is to establish and enforce standards that ensure safe operation of all aspects of the aviation system. Emergency diesel generators operated by the FAA contribute to the safe operation of the National Airspace System [30].

Facilities that must maintain aids to air navigation and traffic control utilize EDGs at all times and under a variety of conditions. If a control site loses offsite commercial power, EDGs and emergency batteries are the only defense against failure of the facility. If a facility fails to operate, air traffic in that area will slow considerably as control is passed to adjacent centers. This situation took place on December 18, 1997 at a control center in Kansas City when a worker inadvertantly shut down both halves of the redudant primary power circuit system while performing routine maintenance. Although the EDGs were operational, the nature of the human error prevented both the diesels and the batteries from providing power to the control station [31]. This type of failure results in inconvenience for air travelers and a loss of revenue for the airlines. A more drastic consequence of a failed facility is the possibility of an air crash due to loss of approach radar or communications. Thus, high reliability and safe operation of the EDGs are paramount to the FAA [32].

5.3.1 General Description

The FAA owns, operates and maintains approximately 3000 standby generators in the US. A majority of the generators operated by the FAA are diesel powered and range in size from 1.5kW to more than 550kW. Most of these units have a fully automatic start system designed to assume the facility load if interruption of the prime offsite power occurs. The FAA utilizes continuous monitoring of operating EDGs to assess the engine for dangerous overspeed, excessive load, high temperature and low oil pressure. Readings outside of the allowed tolerances set for these parameters will automatically shut down the diesel [30].

5.3.2 Maintenance Requirements

Maintenance guidelines and requirements for the diesels operated by the FAA are set forth in *Order 6980.11B: Maintenance of Engine Generators* [30]. This order is a comprehensive guideline that outlines procedures for proper maintenance and inspection of all engine generators utilized by the FAA. The order contains detailed diesel generator information as well as a section tailored specifically for diesels in standby operation.

An initial review of the maintenance requirements detailed in this order reveals what appears to be an enormous number of required action items. However, many of these items are testing requirements which we eliminated for comparison purposes. The remaining items, while thorough, are liberally peppered with visual checks and maintenance items that should be performed "if required."

One notable maintenance requirement that fits into the "if required" category is the overhaul of EDGs and other diesels operated by the FAA. Item 204, which outlines this requirement reads as follows:

> 204. ENGINE OVERHAUL. Check to determine need for overhaul of engine, accessories, and turbocharger. Overhaul if required [30].

The FAA does not determine this need for an overhaul at a pre-determined interval. However, they do require that a qualified technician make this assessment and subsequently determine the depth of a particular needed overhaul. The author of Order 6980.11B stated that while FAA diesels sometimes require major maintenance, overhauls are infrequently, if ever performed. He stated that proper maintenance of the diesels ensures that by the time FAA diesels qualify for an overhaul, the age of the diesel usually justifies replacement of the entire diesel [32].

5.3.3 Enforcement of Standards

The FAA is in a unique situation in that it sets its own standards, implements those standards, and then enforces those standards upon itself. In order to combat a possible conflict of interest, the FAA periodically dispatches technical evaluators to their facilities to gauge the level of compliance of individual facilities with FAA requirements.

One such technical evaluator stressed that although this program provides a certain level of enforcement, its main purpose is to improve the overall performance of the diesels.

The FAA technical evaluator also observed that the FAA's inherent ownership of its diesels is a different relationship from that of the NRC and the utility EDGs. While the FAA regulates and enforces its rules upon itself, the NRC regulates and enforces standards upon the utilities which are independent, separate entities. The technical evaluator judged that this difference may account for the FAA's more liberal approach to the frequency of diesel overhauls [33]. In other words, since the FAA has direct oversight, it can better judge the specific maintenance needs of its diesels. By contrast, the NRC may have extremely stringent rules in order to compensate for utilities with relatively lax standards.

Although the FAA and nuclear utility EDGs are regulated in contrasting ways, the end relationship is not profoundly different. In both cases, the FAA and the individual utilities both have an inherent interest in the good performance of their diesels regardless of the method of regulation. Therefore a more liberal EDG overhaul frequency may be appropriate for individual utilities.

5.3.4 FAA EDG Summary

The FAA demands adherence to a specific, general set of EDG periodic maintenance requirements regardless of the individual manufacturer of the diesel. These general maintenance requirements consist mainly of visual checks and maintenance that diesel operators should perform if they identify a need to do so. The FAA performs overhauls rarely, if ever. Despite this apparently liberal approach to diesel maintenance, FAA diesel generator experts feel that the performance and reliability of these diesels are acceptable. Unfortunately, the FAA has conducted no studies that track the reliability of these diesels. However, the FAA cannot directly link the death of a single human or an aircraft crash to the failure of an EDG at an FAA air traffic control facility.

5.4 The United States Navy

The use of EDGs by the US Navy to provide backup power for nuclear reactors on board ships is notably similar to the use of EDGs in the nuclear industry. The Navy's long history of nuclear power utilization has provided ample opportunity for reassessment and continual improvement of its EDG maintenance requirements. A review of the Navy's current requirements reveals a comprehensive maintenance program as well as a detailed inspection program that explicitly emphasizes non-intrusive practices.

5.4.1 Maintenance History

Until the late 1950s, the US Navy operated under a very reactive-type maintenance environment known as progressive maintenance. Organized maintenance plans were rare and Navy personnel only repaired equipment when broken or malfunctioning [34]. Planned preventive maintenance programs became more widely adopted in the early 1960s [35]. These programs were also fairly reactive in that they established maintenance requirements based upon individual events as failures occurred instead of developing a generalized program that workers could apply to all equipment.

The Navy established preventive maintenance programs because of a belief that this type of maintenance would combat the decreased reliability associated with the increasing age of equipment. However, studies done in the mid-1960s revealed that unreliability did not increase dramatically with the age of the equipment. In fact, the largest problem identified with these studies was the problem of high failure rates of equipment following maintenance (infant mortalities). This discovery prompted the navy to search for a more systematic approach to developing preventive maintenance task needs.

In the early 70's, the Department of Defense adopted a maintenance technique first utilized by the airlines in the maintenance program for the Boeing 747. This technique utilized a decision tree to identify critical maintenance tasks which affected the unreliability of operations. This efficient and systematic approach to preventive maintenance was first applied by the Navy to its newly designed aircraft. Shipboard implementation of this method occurred in 1978 and was termed Reliability-Centered

Maintenance (RCM) by the Navy. Currently, RCM still forms the basis for maintenance performed on shipboard Naval equipment.

The objective of RCM is to maintain the inherent reliability of the equipment design. RCM avoids focusing directly on subsystems and individual equipment and instead concentrates on identifying functionally significant items. Maintenance planners must then determine maintenance tasks for these items based on an analysis of their function and dominate failure modes. Once the planners select a task, they can then determine the specifics of an inspection item like its periodicity. Today these maintenance tasks fall into the following three categories: 1)time-directed tasks, 2)condition-directed tasks, or 3)the do nothing option. Personnel must perform time-directed tasks at specific intervals without consideration of other variables. Condition-directed tasks are performed by workers at specific intervals or after a number of specific events and then observed conditions are compared with an appropriate standard. Finally, RCM may determine that the best maintenance strategy for a particular item may be for no maintenance on a particular item.

In order to develop a schedule for condition-directed tasks, the Navy utilized a tool called age-reliability analysis. Age-reliability analysis is a set of techniques that identify the relationship between system or equipment probability of failure and elapsed times since its manufacture or last complete overhaul. The Navy used this technique in the early 1980s to establish maintenance schedules for the few maintenance tasks that were not time-based.

Recently, the Navy announced that it will move increasingly towards condition-based maintenance. In conjunction with this, the Navy resumed work on age-reliability analysis. A report produced on this subject in 1993 found evidence to support that premature failure following overhaul is common and that evidence of equipment wearout necessitating complete overhaul of equipment is uncommon. In addition, the study found that routinely-authorized overhauls seldom prevent equipment failures [35].

5.4.2 Diesel Generator Maintenance

Although the history of diesel generator maintenance roughly follows the overall maintenance history of the Navy, there is one important difference. In 1987, the Navy established a formal program to provide routine inspections of all diesel engines by qualified Diesel Engine Inspectors (DEI). The Navy established this unique program as a result of an acknowledgment by the Navy that a standardized method of assessment was needed for this vital piece of equipment. The DEI program is not only a successful inspection program but also establishes a central group of experts that Naval personnel can call upon to troubleshoot diesel problems at any time [36, 37].

5.4.3 US Navy Diesel Inspection

Every operational diesel engine in the Navy's inventory must undergo a diesel inspection by a certified DEI every 18 months. This comprehensive inspection includes the following three phases:

> I) Review of Records -- This phase includes a complete review of the engine maintenance history, operating logs, trend analysis, and training of the engine operators.
>
> II) Secured Inspection -- This is a disassembly inspection of the diesel based on the results of the Review of Records. All or part of the Secured Inspection may be waived at the inspector's discretion. If this phase is required, the inspector decides the degree of disassembly and conducts a thorough evaluation of the internal condition of the engine.
>
> III) Operating Inspection - The DEI conducts a thorough review of the engine operating parameters using appropriate technical manuals as a guide [38].

The Secured Inspection phase is similar in makeup to the nuclear industry ROI except that manuals dictating the conduct of this inspection repeatedly emphasize to the DEIs that they should "Keep teardown to the absolute minimum required to accomplish and adequate inspection [36]." This attitude was also expressed repeatedly by a DEI throughout the observation of one such inspection that took place on board a US Navy submarine. The DEI conducting this inspection was careful to point out the merits of minimum intrusion to the emergency diesel. He also pointed out non-intrusive evaluations of the diesel that can identify possible problems within the diesel [37].

One specific issue addressed by the DEI was that of borescoping of the cylinder liners. Although borescope equipment is available within the Navy, inspectors hardly ever use this technology because of its intrusive nature. The Navy only borescopes its cylinders if there are indications that a cylinder is malfunctioning, at which point the Navy judges that the intrusiveness is justified.

An additional goal of the DEI program is to reduce the incidence of human error-induced failure. Of the few EDG overhauls that the interview DEI could recall taking place, a majority of them were required because of some type of human error or intrusion. One particular overhaul, which cost the Navy $7.5 million, was attributed to the introduction of a candy wrapper into a submarine's EDG. The Navy hopes that the presence of the DEI during the diesel inspection provides a barrier to these types of human errors.

The official DEI handbook contains the Secured Inspection phase worksheet for all Colt-Pielstick diesels utilized by the Navy. Although this inspection worksheet applies to both standby and propulsion diesels, the DEI tailors the scope and depth of each inspection to fit the individual diesel inspection [36].

5.4.4 US Navy Automated Diesel Engine Trend Analysis Program

The US Navy recently implemented the Automated Diesel Engine Trend Analysis (ADETA) program on board US ships to provide a means to collect and analyze diesel engine operating parameters. ADETA was designed by the Navy to provide a means of effectively monitoring engine operation as well as determining the need for corrective maintenance and overhaul [39].

ADETA is an automated, personal computer-based system that is capable of tracking several different engine parameters including exhaust temperature, crankcase pressure and vacuum and lube oil pressure. Although this program is capable of troubleshooting parameters considered outside of established parameter bounds, it has received some criticism for its inability to identify harmful trends that remain inside allowed parameter bounds. Currently, diesel operators must still identify harmful trends.

5.4.5 Diesel Overhaul

The results of the inspection performed by the DEI and information gathered from ADETA form the basis for determining the need for a diesel engine overhaul. Navy diesel experts stated that such overhauls usually apply only to diesels used for propulsion and are rarely performed on emergency diesels. In fact, most Navy EDGs go without an overhaul for the life of the ship which can be as long as 30 years. The DEI whom we interviewed judged that this excellent record can be attributed to the expertise and standardization which the diesel inspection program provides [37, 38].

5.4.6 Enforcement

While each Navy ship owns and operates its own EDG, that diesel is subject to Navy-wide standards. The DEI, while a member of the Navy, is not subject to the ship's authority. The Navy instituted this arrangement in order to diminish the possibility of a conflict of interest between the ship's leaders and its diesel operators. A failure to comply with the diesel inspection program's requirements can result in the ship being removed from active service in the Navy. Although this action may seem drastic, a failure of the diesel could result in a loss of life onboard ship or loss of the entire ship. Such an event could affect the Navy's ability to defend the United States against its enemies [37].

5.4.7 US Navy EDG Summary

The United States Navy has taken a systematic approach to improving the reliability of the EDGs onboard its warships. Maintenance practices have continually evolved to incorporate available technology to the point that Navy EDGs rarely need overhauls. This can be attributed in part to a comprehensive inspection program that emphasizes non-intrusive procedures and provides each diesel with a pool of trained experts. This program has produced an impressive record of high availability and has attempted to address the problems of non-availability associated with human error.

5.5 Inspection Requirement Comparison

Although each of the major non-nuclear industry groups reviewed here differ significantly in the ways in which their maintenance and inspection requirements occur, they otherwise share fundamental similarities. First, and most importantly, all three groups rarely perform overhauls on their respective diesel engines. These groups perform inspections regularly but emphasize non-intrusive practices. Many inspection items are visual and depend increasingly on use of modern engine analysis equipment.

All of the similarities cited above contrast distinctly with nuclear power industry EDG practices and ROI requirements. Although it would be an exaggeration to term the ROI a "major overhaul," it does require a significant amount of disassembly, being well beyond the amount required by the non-nuclear power industry groups. A detailed review of individual inspection items revealed that many of the items required by the ROI are performed on a discretionary basis in the non-nuclear industry groups. Table 5.1 presents this comparison.

The first column of Table 5.1 contains the items identified by the MP-3 diesel engineer as benefiting from elimination or change. Numbers listed in this column refer to the current ROI numbering system. The second column contains those items found in the Navy's EDG inspection and overhaul requirements that compare with the ROI items. The numbered items in this column come from the DEI handbook and must be performed by Naval personnel once every 18 months. The remaining items in the second column are Navy overhaul requirements. The final column contains FAA maintenance and inspection requirements similar to the ROI items. Numbers found in this column are maintenance requirement numbers utilized by the FAA.

A quick survey of Table 5.1 reveals that a majority of the items in the Navy column are visual checks or items performed only during a major overhaul. The FAA column is also filled with visual checks and items referred to as incidental. The term incidental refers to items that the FAA performs on a discretionary basis. Although there is a general trend of non-intrusive or discretionary items in columns two and three, the crankshaft measurements are a notable exception. The MP-3 engineer judged that this requirement was very intrusive to the diesel and could be replaced with engine and oil analysis [21]. The Navy DEI considered the crankshaft measurements to be important to his inspection. At this time, however, the Navy does not utilize analysis equipment capable of detecting crankshaft problems.

MP-3 Colt-Pielstick ROI Items Recommended for Change[1]	Corresponding US Navy Requirements[2]	Corresponding FAA Standby Generator Requirements[3]
2. Remove and check injection nozzles for operation and opening pressure.	7.a: Check and record injector fuel pump timing on at least two cylinders on each bank. (18 months)	206.a: Clean and service fuel injectors if required. (Annually)
3. Remove, disassemble, clean and repair all air start valves and air start distributors.	Install complete set of injection equipment. (Major overhaul)	203.d: Inspect starter. (Biennially)
4. Drain and refill governor and turbochargers with approved oil.	3.a: Visually inspect turbocharger oil level and condition of oil through sightglasses. (18 months) 7.b: Check governor oil level and oil leakage around base of governor. Visually inspect oil condition through sightglass. (18 months)	203.b: Drain and replace oil in hydraulic governor sump every two years, or after 200 hours of operation, whichever comes first.
9. Check for tightness of exhaust manifold flange bolts to cylinder head (165-195 ft.lbs).	4.a: Visually examine exhaust system for leaks during operational test. (18 months)	201.i: Examine exhaust and combustion air systems for leaks. (Monthly)
11. Borescope all cylinder liners.	Remove all cylinder liners. (Major overhaul)	Discretionary
14. Perform camshaft bearing analysis.	Remove, inspect, and repair/replace camshaft bearings. (Major overhaul)	Discretionary
15. Check crankshaft alignment and bearing clearances.	2.m: Take a complete set of crankshaft deflection readings and bearing presses. (18 months)	Discretionary
19. Check alternator coils and poles for indication of movement (visual).	No reference.	Discretionary

Table 5.1 Refueling Outage Inspection Items Recommended for Improvement Listed in Comparison to Practices in Other Industries Employing EDGs

([1]current ROI requirements [16] [2]numbering refers to items found in Navy Diesel Engine Inspection handbook [35] [3]numbering refers to items found in FAA maintenance manual[30])

5.6 Summary

A review of non-nuclear industry EDG inspection, maintenance, and overhaul requirements reveals that their programs emphasize non-intrusive, visual inspections. When contrasted with the ROI requirements at MP-3, these observations validate the nuclear experts' opinions that the ROI items are too intrusive and based upon unsound engineering practices.

Chapter 6 -- ROI Implementation Risk and Reliability Implications

6.1 Introduction

The project on *Integrated Models, Data Bases and Practices Needed for Performance-Based Safety Regulation* focuses on three practices that affect the reliability of the EDGs and their related systems as seen in Table 6.1. Monitoring, testing, and inspecting are common practices utilized in numerous engineering applications. Each of these practices are utilized extensively for maintaining the diesels at MP-3. We carefully reviewed the practices currently in place at MP-3 and proposed changes in these practices based on industry comparison and expert opinion. Subsequent risk and reliability analyses were then performed in order to identify potential improvements resulting from the altered practices. This chapter presents the risk and reliability implications of altered inspection practices. Dulick's report details the risk and reliability implications of altered monitoring and testing practices [3].

Our survey of expert opinion has shown that the proposed improved ROI will produce qualitative performance improvements for the EDGs. In order to assess the quantitative benefits of the proposed ROI alterations, it is necessary to calculate the risk implications of the suggested changes. In the case of the ROI alteration, the plant realizes

PRACTICES AFFECTING EDG RELIABILITY	WHAT IS DONE	HOW PRACTICE AFFECTS RELIABILITY OF EDG
MONITORING	The diesel and its support systems are continuously or periodically monitored and tracked with sensing equipment especially during tests. The information provided by this equipment keeps the operators of the diesel apprised of the status of the EDG and related systems.	Monitoring can aid EDG operators in identifying internal failures or harmful performance trends without the intrusiveness of some inspection practices. Utilization of monitoring equipment, however, may introduce new failures modes.
TESTING	The diesel is periodically operated for a specific duration of time according to applicable regulations. The tests provide information on the performance of the diesel and its ability to fulfill its safety function.	Testing ensures that the diesel is able at the time of the test to perform its vital role of supplying backup power and can aid in the identification of failures. Over-testing, however, can unnecessarily stress the diesel. Use of improper testing intervals and run times, as well as the limitations of some tests, can prevent identification of important failure modes.
INSPECTION	The diesel and related systems are periodically inspected in order to identify excessive wear and latent failures. Inspection also ensures that preventive maintenance is being performed correctly.	Inspecting the EDG can aid in the prevention of failures due to wear or poor manufacture. Improper or over-inspecting, however, can introduce failure through part warping, improper disassembly or reassembly and numerous other possible human errors.

Table 6.1 Practices Affecting EDG Reliability

a net benefit as a result of changes in the various risk factors affected by the proposed changes.

In order to estimate these risk changes we first perform a time savings calculation in order to assess the risk benefits realized within the refueling outage. The significant time savings realized by an improved ROI positively impact the fuel melt frequency (FMF) of MP-3, as well as the qualitative level of defense in depth (DID) in the plant. Although a shortened ROI does not affect the critical scheduling path of MP-3, calculations show that this is a possible future benefit realized by the plant. It also affects EDG availability, which has an effect upon other allowed activities and their risk.

A sensitivity analysis of the reliability improvements associated with the Improved Refueling Outage Inspection (IROI) reveals significant potential reduction of the EDG system failure probability. In addition to this, we present the results of a similar analysis of the effects of increased EDG monitoring and its use as justification for an increase in EDG surveillance interval and a change of test duration.

6.2 Time Savings Calculation

Here we calculate the time savings associated with the IROI. This calculation is an essential part of our analysis as the resulting time savings impact both the fuel melt frequency of the plant and the defense in depth in the plant.

A team of workers that includes mechanics, laborers, a Colt-Pielstick service representative, and the diesel engineer perform the ROI and associated maintenance at MP-3. At any given time, there are three to four workers executing the planned ROI items. With these workers laboring around the clock in staggered ten hour shifts, the ROI for each EDG is completed by the laborers in about seven days.

In order to calculate the man-hour savings realized by the IROI, we asked the MP-3 diesel engineer to give his best estimate of the number of workers and time currently required to perform the individual items that he recommended for alteration [21]. We calculated the total time saved for each item altered according to Equation 6.1.

$$\begin{pmatrix}\text{Laborers}\\\text{Required}\end{pmatrix}\times\begin{pmatrix}\text{Time}\\\text{Saved}\end{pmatrix}\times\begin{pmatrix}\text{Periodicity}\\\text{Factor}\end{pmatrix}=\begin{pmatrix}\text{Total Time}\\\text{Saved}\end{pmatrix}\qquad(6.1)$$

The Periodicity Factor (PF) contained in Equation 6.1 is a positive multiplicative factor, less than or equal to unity, which indicates the frequency at which inspection items are currently performed. The PF is equal to unity for items the ROI requires every refueling outage. Items recommended for periodicity extension to once every other refuel have a PF equal to one half.

Table 6.1 contains the MP-3 diesel engineer's estimates of the time savings associated with individual inspection item alteration. Additionally, Table 6.1 contains the diesel engineer's estimate of the number of workers involved with the individual inspection items. Utilizing Equation 6.1, this information is then used to find the total time saved for each altered inspection item. The results of the calculation can also be found in Table 6.2.

Item # From Current ROI Checklist	CURRENT REQUIREMENT	LABORERS REQUIRED	TIME REQUIRED	TOTAL TIME SAVED BY ALTERATION OF THIS ACTIVITY
2	Remove and check injection nozzles for operation and opening pressure.	2 workers	30 hours (3 shifts)	60 hours
3*	Remove, disassemble, clean and repair all air start valves and air start distributors.	2 workers	15 hours (1.5 shifts)	*15 hours
4*	Drain and refill governor and turbochargers with approved oil.	1 worker	1 hour	*0.5 hours
9	Check for tightness of exhaust manifold flange bolts to cylinder head (165-195 ft.lbs).	2 workers	10 hours (1 shift)	20 hours
11	Borescope all cylinder liners.	1 worker	8 hours	8 hours
14*	Perform camshaft bearing analysis.	1 worker	6 hours	*3 hours
15	Check crankshaft alignment and bearing clearances.	2 workers	20 hours (2 shifts)	40 hours
19	Check alternator coils and poles for indication of movement (visual).	3 workers	20 hours (2 shifts)	60 hours
			TOTAL	206.5 hours

Table 6.2 Factors of Estimated IROI Labor Time Savings

Based upon the MP-3 diesel engineer's estimates of individual item time savings, the total person-hour savings associated with the IROI is 206.5 man-hours. This value is the total of the estimated labor hours located in column 5 of Table 6.2. We note starred items with a Periodicity Factor not equal to unity in order to highlight their uniqueness. For example, Item 3, disassembly and cleaning of the air start valves, usually requires approximately 30 person-hours to perform. The IROI involves only inspecting half of the valves during each inspection, which requires only 15 man-hours to perform. Thus we entered the 15 hour estimate in Table 6.2.

In order to arrive at a time estimate that is useful for risk analysis calculations, we must translate the total man-hour savings into saved inspection hours. This is done by dividing the total man-hour savings by the number of workers performing the inspection at any one time as indicated in Equation 6.2.

$$\begin{pmatrix}\text{Total Time}\\ \text{Saved}\end{pmatrix} \div \begin{pmatrix}\text{Number of Workers}\\ \text{Performing Inspection}\end{pmatrix} = \begin{pmatrix}\text{Inspection Hours}\\ \text{Saved}\end{pmatrix} \tag{6.2}$$

The MP-3 diesel engineer indicated that three to four workers are performing the inspection at any given time. For this evaluation, we used the average number of workers, or 3.5 workers, as the number of workers performing the inspection. Using this average number of workers results in 59 inspection hours saved or approximately 2.46 inspection days saved.

The MP-3 diesel engineer indicated that the inspection team usually completes the current ROI, which is typically scheduled for a seven day period, within five days. He estimated that an improved ROI that adopts the proposed alterations could be scheduled for five days and would actually take about three days to complete [21]. The above calculations indicate that the improved ROI will take about 2.54 days to complete (estimated five days less 2.46 inspection days saved) indicating that the MP-3 diesel engineer's estimate is slightly conservative.

We use a time savings of 59 hours throughout this work to estimate the IROI's impact on risk.

6.3 Defense in Depth

Concern within the nuclear power industry regarding the adequacy of Technical Specification (TS) requirements during plant outages prompted our review of the development and bases for these regulations. This review, along with a survey of industry experience, found that the NRC did not base TS for shutdown conditions upon exhaustive safety analyses like those required for operations at power. This discovery prompted the formulation of additional system requirements designed effectively to manage outage risk [40, 41]. Defense in depth (DID), a strategy commonly used by the military to protect vital assets, is one concept adopted by the nuclear power industry in order to compensate for uncertainty in the TS. Today the NRC endorses and encourages the use of this refueling outage planning strategy.

The DID concept as utilized at MP-3 aids in the planning and scheduling of outage activities in a manner that improves safety system availability. At MP-3, outage planners use DID as a risk management criterion in order to ensure that redundant, alternate or diverse methods are used to ensure that the Key Safety Functions (KSF) of the plant are protected [42].

The KSF concept is an additional risk management approach that requires MP-3 to identify the safety systems that are essential for safe operation during an outage. The KSF at MP-3 are the Decay Heat Removal, Inventory, Containment, Electrical Power, and Reactivity control systems. For each of these functions, MP-3 established a set of color-coded DID criteria that defines a level of protection as follows:

Green -- Signifies a condition in which equipment or system redundancy is greater than the minimum DID standard.

Yellow -- Signifies a condition in which equipment or system redundancy is is equal to the minimum DID standard.

Orange -- Signifies a condition in which equipment or system redundancy is is one requirement less than the minimum DID standard.

Red -- Signifies a condition in which equipment or system redundancy is is two or more requirements less than the minimum DID standard.

Guidance for the establishment of actual DID levels for the KSF is provided by the NUMARC 91-06 document, *Guidelines for Industry Actions to Assess Shutdown Management* [43]. The minimum DID power availability condition (yellow status) requires the maintenance of one available EDG and one offsite power source as well as one backup power source. At MP-3, the offsite power sources include the normal station transformer (NSST) and the 'A' reserve station transformer (RSST). Backup power sources at MP-3 include the unused EDG, the redundant offsite power source and the station blackout diesel (SBOD). The SBOD is a non-safety grade diesel capable of carrying a limited number of critical safety loads that can be started should both the A and B EDG fail under Loss of Offsite Power (LOOP) conditions, thereby leading to a station blackout condition. Figure 6.1 is the Shutdown Safety Assessment Checklist used by MP-3 to determine its DID level for power supply redundancy.

Date:________________ Time:____________________

IV. **Power Availability**

Need at least one offsite source, one EDG, and one other.

- ☐ A EDG (1) ______
- ☐ B EDG (1) ______
- ☐ RSST (1) ______
- ☐ NSST/MAIN (1) ______
- ☐ Station Blackout EDG (1) ______

Power Total ☐

TOTAL	**CONDITION**
0 - 1	**Red**
2	**Orange**
3	**Yellow**
4 - 5	**Green**

Figure 6.1 MP-3 Shutdown Safety Assessment Checklist for Emergency Power Redundancy [42]

MP-3 outage planners never deliberately plan to exceed the minimum DID level when determining the outage schedule. In other words, the plant will only enter orange and red DID levels inadvertantly, as when equipment is unexpectedly removed from service or when scheduled maintenance is not completed in the allotted time. At MP-3, the goal of outage planners is to remain in the green DID space as much as possible [41].

During the April 1995 refueling outage, the maintenance and inspection of the electrical power supply system was scheduled for 611 hours. Of this 611 hours, 230 hours were scheduled for DID level yellow while the remaining 381 hours were scheduled for DID level green. These hours correspond to 62.4% at DID level green and 37.6% at DID level yellow during the electrical power supply system maintenance period. Figure 6.2 details the DID levels scheduled during MP-3's 1995 outage. This figure provides a compacted view of the refueling outage schedule found in Figure 3.2 with overlapping scheduled maintenance superimposed onto a single time bar. The resulting figure indicates the periods of time in which equipment outages result in different DID levels. Additionally, this figure indicates the equipment outages that result in a yellow DID level [20].

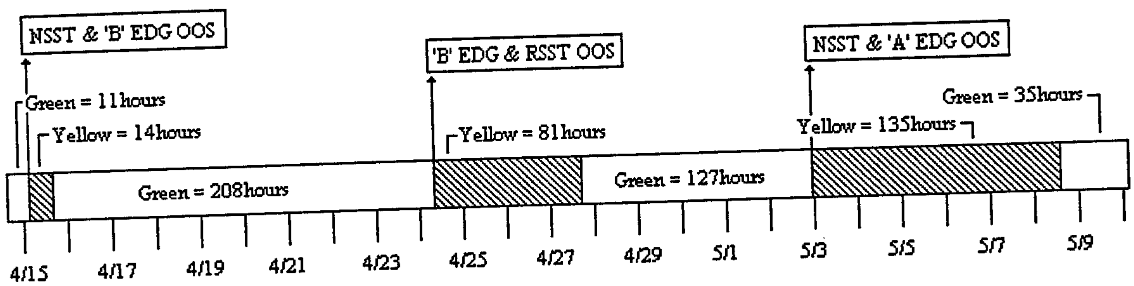

Figure 6.2 DID Levels for MP-3 1995 Refueling Outage

6.3.1 Defense in Depth Improvements

Significant defense in depth improvements are realized when we apply the IROI time savings to the outage schedule.

In 1995, the outage times for the A and B EDGs were 170 hours and 172 hours, respectively. Application of the IROI time savings shortens these outages to 111 hours for the A EDG and 113 hours for the B EDG. Figure 6.2 indicates three periods when the plant was in DID level yellow. The first and third yellow DID levels are directly affected by the shortened EDG inspections. The second DID level is not affected by the shortened EDG inspection because the B EDG is out of service as a consequence of the outage of bus 34D, not because the B EDG is non-operable due to maintenance. Figure 6.3 shows the 1995 Refueling Outage, modified due to application of the IROI. It indicates a reduction of the yellow DID level due to the time saving associated with the changed EDG inspection.

Figure 6.3 shows that the first yellow DID level found in Figure 6.2 is entirely eliminated as a consequence of the shortened EDG inspection of the B EDG. The second yellow DID level of Figure 6.2 is left unchanged because of the "out of service" status of

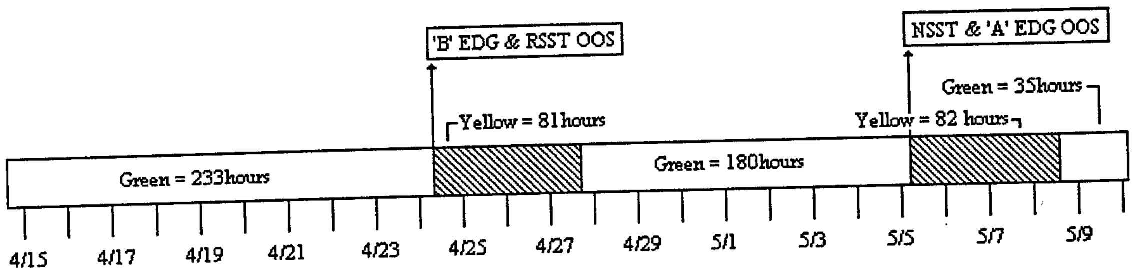

Figure 6.3 IROI-Modified 1995 Refueling Outage DID Levels

bus 34D. The shortened A EDG inspection reduces the final yellow DID level from 135 hours to 82 hours.

Further reduction of the last yellow DID level is limited by the outage of bus 34C. Bus 34C has the same effect upon the A EDG that bus 34D has upon the B EDG in that its outage renders its associated EDG essentially non-operational. Buses 34D and 34C both transmit power generated by the EDGs to the vital safety loads. If they are incapable of transmitting this power, the status of the EDG is irrelevant to whether the system can provide electric power. The limitations placed upon further DID level improvement as a result of the bus outages indicate that further time savings associated with the EDG inspections would produce no further DID level improvement. In other words, the currently proposed IROI results in the maximum DID improvement possible due to alteration of the EDG inspections.

The DID levels shown in Figure 6.3 result in an overall green DID level increase to 73.3% of the total outage reflecting an improvement of 17.5%. This large increase indicates a significant DID capability improvement. Essentially, MP-3 would remain at the highest level of DID for almost three quarters of the electrical system outage. Table 6.3 further summarizes the DID level improvements associated with the IROI.

Outage Inspection Requirements	**DID Level Green** (hours/%)	**DID Level Yellow** (hours/%)
ROI	381 hours / 62.4%	230 hours / 37.6%
IROI	448 hours / 73.3%	163 hours / 26.7%

Table 6.3 DID Level Comparisons for the 1995 Refueling Outage Subject to ROI and IROI Requirements, Respectively

6.4 Refueling Outage Risk Improvement

Risk reductions during the refueling outage of a plant are two-fold when MP-3 utilizes a shortened EDG inspection. Initially, the IROI will alter the risk profile of a plant's scheduled outage resulting in a lower probability of fuel damage. A shortened inspection can also conceivably shorten the critical path of the refueling outage yielding significant economic benefits for the plant.

The primary measure of risk during a plant refueling outage is the risk of fuel damage. While the plant is in a shutdown status, the spent fuel must be continuously cooled until it is removed from the core. This cooling process is accomplished through the constant circulation of a coolant through the reactor vessel. A loss of cooling will result in eventual boiling and evaporation of the coolant. If cooling is not restored (an action highly dependent upon human intervention), the coolant will continue to evaporate until the fuel is exposed at which point the fuel is damaged. The three primary modes of failure that can cause eventual damage of the fuel during a refueling outage can be seen in Figure 6.4. The loss of cooling fault tree displayed here shows that the three modes of failure are loss of coolant flow, loss of heat sink, and loss of coolant. Both the loss of coolant and loss of coolant flow modes depend heavily upon the proper function of pumps. In the case of a loss of offsite power, these pumps depend upon the proper function of the EDGs. When the EDGs are unavailable due to maintenance or testing, the risk of fuel damage increases significantly [40]. This aspect of diesel unavailability can be clearly seen in the risk profiles in the following section.

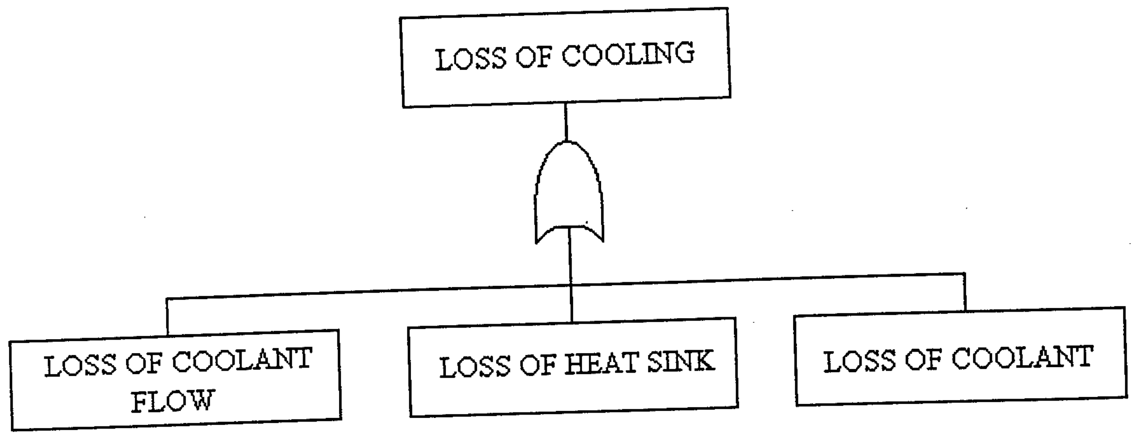

Figure 6.4 Fuel Loss of Cooling Fault Tree

6.4.1 MP-1 Risk Profile

Although MP-3 produced a risk profile for its 1995 refueling outage, the risk profile generated is a relative representation of risk, with no calculated base-line risk being estimated [41]. In addition to this qualitative risk profile, a computer program is utilized at MP-3 that quantifies the core damage frequency. This program, however, was found not to be useful by Millstone PRA experts because of its extreme conservatism [40]. Consequently, no reliable risk quantification tools are available for MP-3's 1995 refueling outage.

Despite this lack of analytical capability, MP-3 will still gain risk reducations with utilization of a shortened inspection. The EDGs are one of the largest contributors to risk when the plant is operating at power and during the refueling outage. Any reduction in the un-availability of the EDG will decrease the overall probability of core damage. This is typical of all plants in the US.

In order to demonstrate the potential improvements of a shortened EDG inspection, we use the risk profile of MP-1's refueling outage [40, 44], as seen in Figure 6.5, as a substitute for the MP-3 risk profile. Utilization of the MP-1 risk profile allows us to quantify the potential risk reductions associated with the IROI, a capability that is unavailable with the qualitative MP-3 risk profile. The MP-1 emergency power system is similar to the MP-3 plant in that it has two EDGs with an additional station blackout generator (gas turbine driven). The risk profile shown was planned for November and December of 1995.

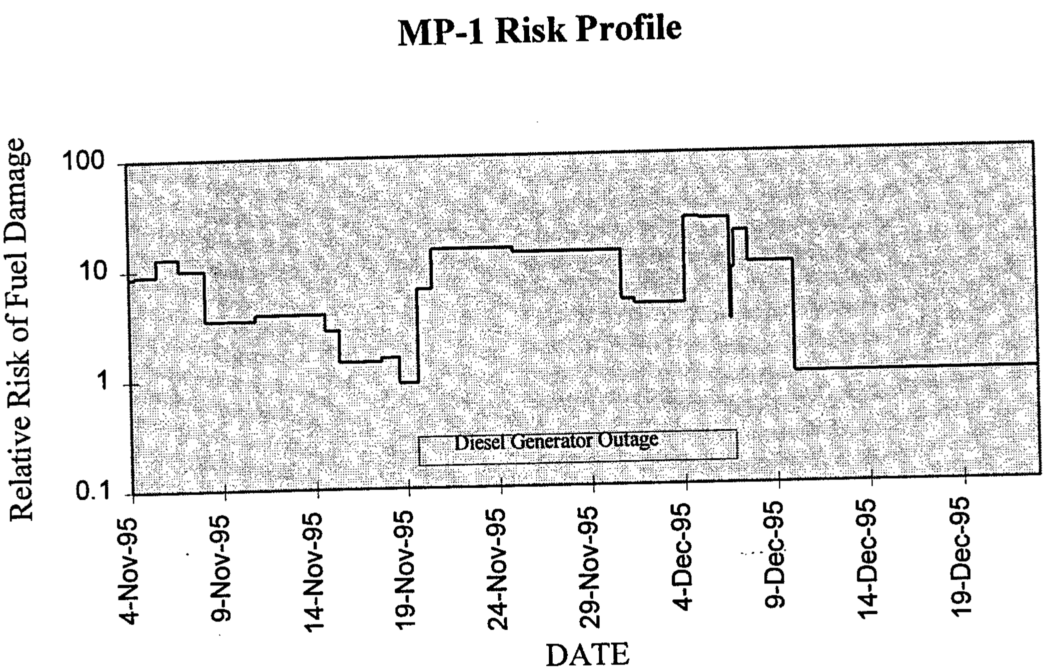

Figure 6.5 MP-1 1995 Fuel Damage Risk Profile

Figure 6.5 illustrates the many risk highs and lows experienced by the plant during a typical refueling outage. The time bar located in the middle of the chart represents the time that the MP-1 EDGs are out of service for maintenance, a period of approximately 17 days or 8.5 days per EDG. MP-3 removes the EDGs from service sequentially so that only one diesel is out of service at one time. The variations in the risk over the EDG outage period are due to various non-EDG equipment being taken in and out of service simultaneously with the EDGs. The baseline risk for MP-1, viewed at the end of the plot in Figure 6.5, is 2.3e-07/day (8.65e-05/year). The baseline risk is the lowest value of risk experienced by MP-3 during the refueling outage. It occurs when there is low decay heat and all safety systems and associated equipment are available to the plant.

The outage of each EDG contributes a multiple of 4.43 over the baseline fuel damage frequency which means that risk of fuel damage is roughly four times more likely when MP-3 removes a single EDG from service. The overall probability of fuel damage during the 49 day refueling outage for MP-1 is 7.993e-5. This value is equal to the area under the risk profile curve. Equation 6.3 aids in the determination of the EDG outage

$$\begin{pmatrix}\text{Baseline}\\ \text{Risk}\end{pmatrix} \times ((\text{Relative Risk}) - 1) \times \begin{pmatrix}\text{EDG Days}\\ \text{Out Of}\\ \text{Service}\end{pmatrix} = \begin{bmatrix}\text{Contribution to}\\ \text{Total Risk}\end{bmatrix} \qquad (6.3)$$

contribution to the overall probability of fuel damage. Utilization of this formula yields a contribution value of 1.335e-5 or 16.7% of the total probability of fuel damage. A reduction in the out of service time for the EDGs results in a overall fuel damage probability reduction and a corresponding decrease of the EDG contribution to the overall fuel damage probability.

6.4.2 MP-1 Risk Profile Improvement

We can credit the 118 hour EDG inspection time reduction at any point in the scheduled outage. Outage planning experts would most likely take several factors into account, DID for example, when scheduling the shorter inspections. Regardless of the scheduling strategy selected, the overall probability of fuel damage reduces by the same amount (assuming that the equipment outages are independent). The improved risk profile displayed in Figure 6.6 applies the 118 hour time credit to the end of the originally scheduled diesel outage.

The new probability of fuel damage, utilizing the reduced inspection requirements, integrated over the 49 day refueling outage is 7.492e-5 which reflects a risk improvement of 6.27%. The EDG outage contribution to the probability of fuel damage is 9.497e-6 or 12.7%. This reflects a reduction of five percentage points. These probability improvements indicate that the shortened EDG inspection not only decreases the overall probability of fuel damage but also decreases the importance of the EDG outage as a contributor to the overall plant risk.

Improved MP-1 Risk Profile

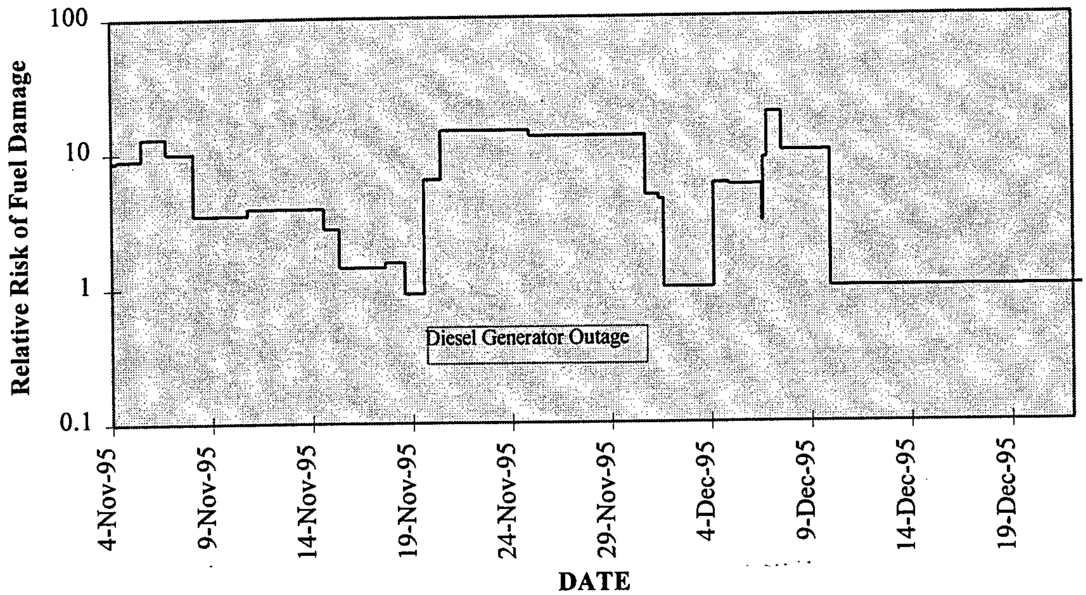

Figure 6.6 MP-1 Risk Profile Showing the Effects of Reduced Inspection Requirements

These same types of improvements would be experienced by MP-3 if it were to adopt the IROI. Although the exact values of probability reductions would differ, it is apparent from the risk profile demonstration that any decrease in EDG outage time will result in risk reductions. In the case of MP-3, it is likely they will experience larger probability reductions as the proposed 118 hour time savings represent a larger portion of the total EDG outage time at MP-3.

6.4.3 A Shortened Refueling Outage

Both the DID and fuel damage probability analyses do not address the risk effects of shortening the overall length of the refueling outage. In actuality, a shortened refueling outage is a natural consequence of a shortened EDG inspection. In this section, we calculate the potential risk reductions associated with the shortened refueling outage.

The IROI of the EDG can be used by the refueling outage schedulers to shorten the electrical power supply system maintenance and testing period. If the electrical power supply system outage is part of the plant critical path, this time savings can translate into an overall shorter refueling outage. In the past, MP-3's electrical power supply system has not been part of the critical path because of problems with the plant's service water system. MP-3 is currently taking steps to repair the service water system, at which time the electrical power system will become part of the critical path [21, 41].

Figure 6.7 shows a revised electrical power supply system schedule that maintains the current DID levels utilized by MP-3 while simultaneously reducing the scheduled outage time. This analysis allowed us to trim the original schedule of 611 hours by 82 hours to a total outage time of 529 hours. This type of schedule could potentially save MP-3 more than three days of its current refueling outage. These time savings are significant and can translate into large monetary savings for MP-3.

A shortened refueling outage can also translate into benefits for the MP-1 refueling outage probability of fuel damage. The shorter outage time period would reduce the number of days needed by MP-1 to complete the outage therefore reducing the total fuel damage risk (the area underneath the risk profile curve). Again, similar conclusions can be drawn for expected changes in the refueling outage probability of fuel damage at MP-3.

6.4.4 Refueling Outage Risk Improvement Summary

In practice, a group of refueling outage planning experts would attempt to maximize the benefits of all three types of refueling outage risk improvements associated with the IROI. DID, safety, and plant economics would all influence the final form of the new refueling outage schedule. Regardless of the final form of this schedule, the IROI allows MP-3 to improve its overall refueling outage risk measurably.

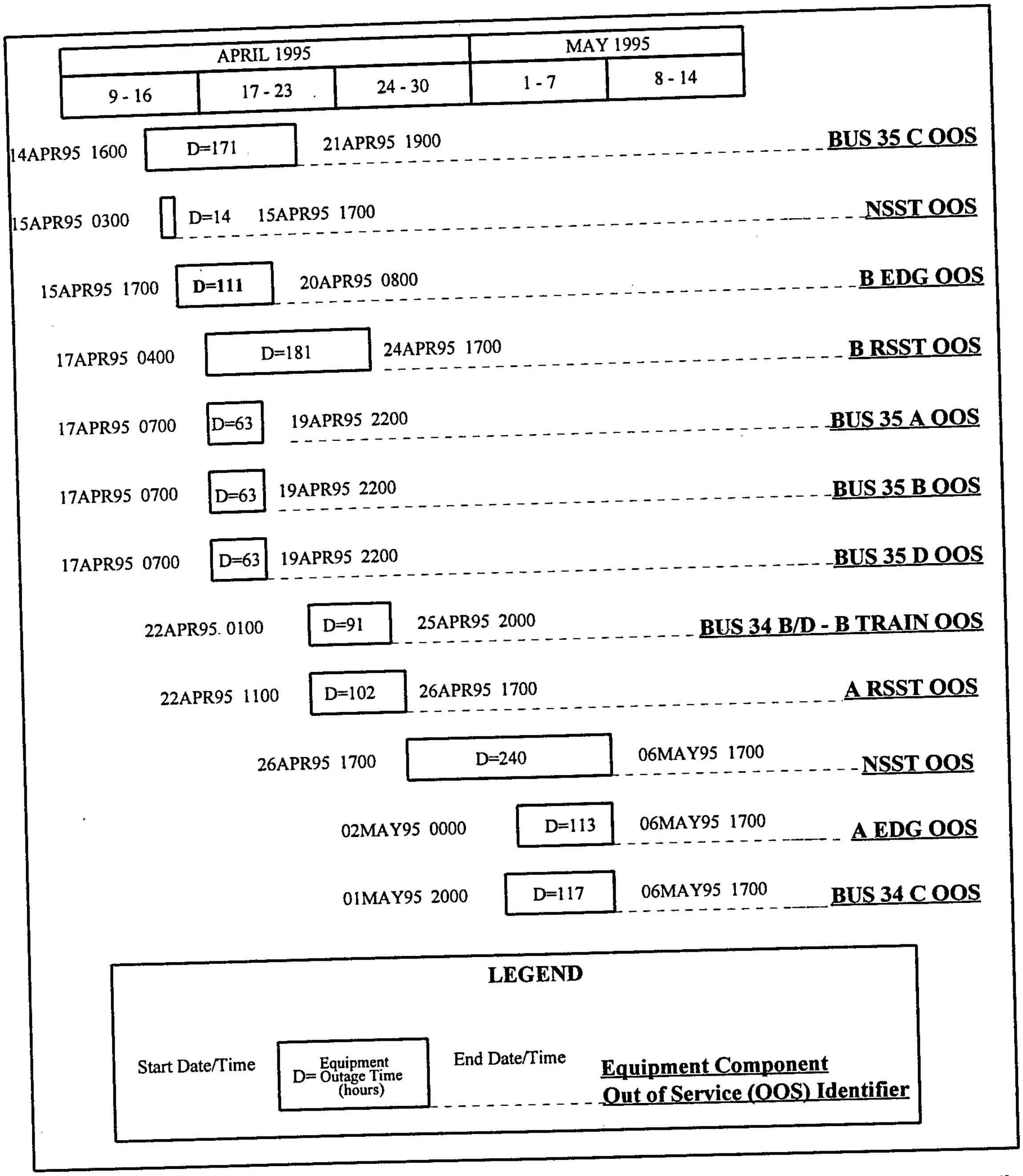

Figure 6.7 Revised Electrical Power Supply Refueling Outage Schedule, Based Upon a Shortened EDG Inspection

6.5 Effects of IROI on EDG Failure Probability

In order to estimate the effects of the IROI upon the EDG failure rate, we must translate the alteration of the required inspections into a change in the failure rates of the basic events associated with the EDG system. Basic events refer to individual failures that could lead to the failure of the entire system (The entire list of MP-3 basic events that contribute to the EDG system failure probability as well as the associated system fault tree can be found in Appendix C [45, 46]). Once we identify the basic events, we can perform a sensitivity analysis in order to evaluate the effect of the basic event changes on the EDG failure rate.

The proposed IROI reduces the probability of failure for four types of basic events at MP-3. Table 6.3 lists the four basic events affected by the proposed IROI for the A EDG as well as their associated respective probability values. In order to calculate the reduction of the EDG system failure probability value, we recalculate the fault tree top event probability value using new values for the four basic events listed in Table 6.4. The new values for the four basic events reflect probability reductions of 25%, 50%, 75% and 100%, respectively.

Basic Event Number	Description	Event Probability
38	EDG A unavailable due to test or maintenance.	1.1e-2
39	EDG A fails to start on demand (includes failure to run).	1.64e-2
68	Common cause failure of air operated start valves.	1.36e-4
69	Common cause failure of EDGs to start on demand (includes failure to run).	1.12e-3

Table 6.4 Basic Events Affected by Proposed IROI and Their Respective Probability Values

Figure 6.8 displays the results of the sensitivity analysis plotting the value of the probability of the top event, failure of the EDG system. The five calculated values of the top event appear as points on the plot with a least-squares best fit line revealing a linear relationship. For example, an anticipated basic event reduction of 50% would decrease the EDG system failure probability 13.9%, from 0.0952 to 0.082.

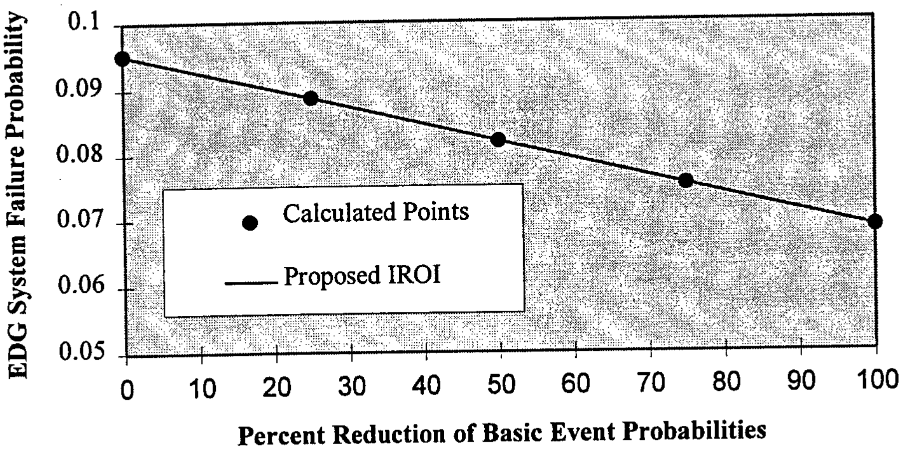

Figure 6.8 Effect of Basic Event Reduction on Diesel Failure Probability

A similar analysis of the introduction of a comprehensive diesel monitoring system at MP-3 revealed that the EDG system failure probability can be driven lower than the values shown for the IROI calculation. The proposed monitoring program included reduction of the probabilities of 21 basic events including three of the four events listed in Table 6.3. In addition to the EDG fault tree basic events, the proposed monitoring system reduced the probabilities of basic events associated with the plant service water pumps and the EDG building ventilation dampers. The risk sensitivity analysis of this system revealed that a 50% reduction in basic event probabilities reduced the EDG system failure probability by 38.6%. Using this new failure rate information, a completely new testing regiment was proposed by Dulik. An hour long monthly run of the diesels was modified to a yearly 24 hour run of the diesel. The increased duration of the test was justified because of its success in identifying nearly 100% of all of the EDG failure modes (in contrast to the 34.5% of modes identified in an hourly run). The decreased frequency of the testing to once per year was established through optimization of the new failure rate and EDG unavailability due to testing. A complete analysis of the proposed monitoring system and its associated reliability improvements and modified testing regiment can be located in Dulik's report [3].

6.5.1 Failure Rate Summary

The reduction in the probabilities of the basic events associated with the improved ROI are unknown quantities. However, the reduction of the failure probability is highly likely as the proposed inspection alterations are based upon sound engineering practices and the extensive historical performance of the MP-3 diesels. The sensitivity analysis presented here quantifies the possible reliability improvements that the MP-3 EDGs may realize with the implementation of the IROI. It is important to note that any reliability improvement experienced by the EDG system will also reduce the core damage frequency (CDF) of the plant.

6.6 Risk Improvement Summary

In order to fully appreciate the benefits of the EDG IROI, analysis must go beyond the qualitative. Risk analysis provides a method for quantitative assessment of the proposed changes. The time savings of the IROI result in improved DID at MP-3 as well as the potential for a shortened critical path. The refueling outage risk profile of MP-3 would also likely benefit from the IROI as reflected in a reduced fuel damage probability. Expert analysis would integrate all three of these refueling outage improvements into a schedule that maximizes the benefits of the IROI.

Although we cannot accurately calculate the reliability effects of the IROI without the actual implementation of the shortened inspection, a sensitivity analysis of the potential improvements provides a clear picture of the possible reliability improvements. Increased monitoring also contributes positively to the risk outlook of the MP-3 EDG system reliability.

Chapter 7 -- On-Line EDG Inspection Benefits

7.1 Introduction

Recent investigation of refueling outages by industry experts has revealed that the probability of a loss of offsite power and therefore the demand for backup power provided by the EDGs may actually be higher during the refueling outage than when the plant is at power [15]. This development is likely due to an increase in the probabilities of human errors associated with odd and infrequently used plant configurations and the associated un-familiarity of workers with them. This situation supports the possible transfer of all EDG inspections, surveillances, and maintenance items that currently remove the diesels from service during the refueling outage to a new practice of execution when the plant is operating at power. Maintenance and testing items performed while the plant is operating at power are known as on-line surveillances.

Several plants in the US have applied to the NRC to alter their respective TS in order to accommodate the 18 month EDG inspection while operating at power. In most cases, this requires an extension of the individual plant's allowed outage time (AOT). We found that for the EDG inspection transfer, the increase in risk associated with a larger AOT is considered non-significant according to NRC criterion established for TS alteration [47]. We also found that the elimination of the EDG ROI significantly reduces the fuel damage probability for the duration of the refueling outage.

7.2 Pilgrim Nuclear Power Station Proposed TS Changes

The Pilgrim Nuclear Power Station (PNPS) is currently applying to the NRC for extension of their EDG AOT from three to 14 days. This extension is intended to increase the repair and preventive maintenance time and to reduce potential for plant shutdown transients during EDG repair and maintenance. Additionally, the 14 day AOT will allow for the performance of on-line EDG maintenance. In order to balance the availability of plant systems associated with electric power activities, PNPS is simultaneously applying for an AOT reduction for the start-up transformer. In other words, PNPS is requiring that their own start-up transformer be more available in order to compensate for the increased unavailability of the EDG [4, 47].

The baseline CDF value at PNPS is 2.84e-5/year, resulting in a core damage probability (CDP) of 1.09e-6 over a 14 day period. The CDF value with one EDG unavailable and one EDG subject to random failures increases by a factor of 1.79 to 5.08e-5/year. The corresponding CDP over 14 days is 1.95e-6, representing a temporary increase of 8.6e-7 (or 78.9%) over the baseline CDP value. This increase is considered non-risk-significant in terms of the criteria of both EPRI and the NRC [4]. EPRI's risk-significant standard is 1.0e-6 for CDP while the NRC standards requires a CDF increase less than 1.0e-5. The CDF increase anticipated by PNPS is 1.72e-6. At this time, the PNPS staff expresses confidence that their proposal will be approved by the NRC [47].

7.3 On-line Transfer of Surveillances at MP-3

The transfer of all MP-3 refueling outage EDG surveillances on-line would first require a basic change in the TS of the plant. Currently, the 18 month inspection must be performed during the refueling outage per the wording of TS 4.8.1.1.2.g.1 [17]. If the TS were changed, however, the MP-3 diesel engineer has expressed confidence that all inspection and maintenance items currently performed during the ROI could be performed on-line with little or no difficulty. The MP-2 diesel engineer supported this opinion, but with the caution that an associated increase in MP-3's three day AOT must occur in order to compensate for the additional surveillances that would be performed on-line [21]. Additionally, he recommended that this increase in the AOT would be beneficial in the event that a major repair must take place [23].

Calculation of the associated risk implications for the transfer of the ROI items and associated EDG testing practices on-line for both the current ROI and the IROI is possible. We present risk calculations in this segment that only address the risk implications of transfer of the IROI. Transfer of the ROI would yield similar risk results but the diesel would not realize the reliability benefits of the altered inspection.

7.3.1 Refueling Outage Risk Improvements

The transfer of the IROI items and associated testing requirements will not affect the calculated IROI DID level improvements during the refueling outage. The current DID levels are constrained by the outage of key buses that will remain unaffected by the transfer of EDG surveillances on-line. This is also true for the critical path time improvements. The improvements computed in Section 6.4.3 represent the maximum refueling outage time savings available with the constraint of maintenance of current DID levels.

The main refueling outage risk reduction of on-line surveillance transfer can be seen in the refueling outage risk profile and associated fuel damage probability. In order to demonstrate this benefit, we again utilize the MP-1 Risk Profile in the absence of a similar MP-3 document. Figure 7.1 details the risk profile alteration anticipated as a result of the transfer of EDG surveillances on-line. The total fuel damage probability over the 49 day outage is 6.27e-5 compared to the original fuel damage probability of 7.993e-5. This change reflects a 21.6% improvement over the base case. This risk profile analysis does not account for risk changes associated with a shortened refueling outage. However, a shortened refueling outage results in additional risk benefits.

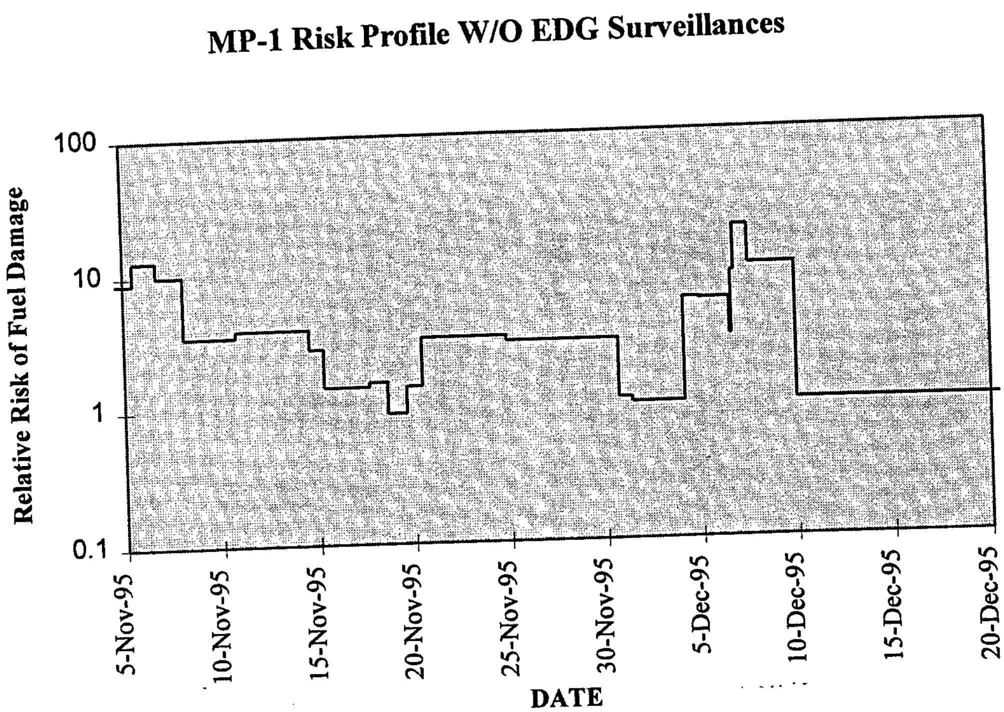

Figure 7.1 MP-1 Refueling Outage Risk Profile in the Absence of EDG Surveillances

7.3.2 Risk Implications of Performing Inspections While Operating At Power

The outage of one EDG at MP-3 increases the CDF a factor of 1.47 over the baseline CDF value of 6e-5/yr [40]. This factor considers the case where one EDG is out of service while the remaining diesel is available but subject to random failures. In order to analyze the affects of transferring EDG surveillances on-line, we must choose a value of AOT increase to use in our analysis. Currently, the MP-3 AOT value is three days but the transfer of the IROI will require at least an extra three days of AOT. One extra day is also added for conservatism and to conform to the MP-2 diesel engineer's suggestion.. No attempt to compensate for power system availability is made here (as in the Pilgrim application). The corresponding risk sensitivities are summarized as follows:

• Baseline CDF	= 6e-5/yr
• Baseline CDP integrated over 7 days	= 6e-5*7/365 = 1.15e-6
• CDF with one EDG unavailable	= 8.8e-5/yr
• CDP with one EDG unavailable integrated over 7 days	= 8.8e-5*7/365 = 1.69e-6

Thus, having one EDG unavailable for 7 days causes a temporary increase of 5.4e-7 over the baseline CDP value. We calculate the permanent change in the annual mean CDF as a result of the increased AOT as follows:

CDP with one EDG unavailable 7 days = 1.69e-6
New annual mean CDF = 2*1.69e-6+(6e-5*351/365) = 6.11e-5/yr.
(The 2* factor is due to the 7 day AOT for EACH diesel)

The resulting increase in the CDF value is 1.1e-6/yr, a figure well below the NRC criterion of 1.0e-5/yr [2].

Table 7.1 contains the projected risk comparison of a 7 day AOT at MP-3 to that of a 14 day AOT. Although a 14 day AOT would meet the NRC criteria, it fails to meet the EPRI criteria of CDP increase less than 1.0e-6 [4]. This criteria failure, however, is quite small and would most likely be waived in practice on the basis that the error of the CDF estimate is less than the CDF difference observed here.

	7 Day AOT	**14 Day AOT**
Baseline CDP	1.15e-6	2.3e-6
CDP w/ One EDG OOS	1.69e-6	3.38e-6
CDP Increase	5.4e-7	1.08e-6
New CDF	6.11e-5/yr	6.22e-5/yr
CDF Increase	1.1e-6/yr	2.2e-6/yr

Table 7.1 Comparison of the Risk Implications of 7 and 14 Day AOTs

7.3.3 Additional Considerations

Before accepting on-line EDG surveillance at MP-3, we must account for additional considerations of risk. Initially, workers will be inexperienced with performing surveillances on-line. The power plant managers must anticipate and reduce human error wherever possible. Additionally, the performance of increased on-line testing may introduce transients that have never occurred before in the plant. The power plant managers must also anticipate and plan for these events. One final consideration is the detailed planning that must take place in order to anticipate equipment outage combinations that would degrade safe operation of the plant. Increased EDG outages while operating at power will necessarily complicate the work of maintenance planners [15, 21, 23, 40].

7.4 Summary

Use of on-line testing and maintenance in nuclear power plants has increased greatly in recent years. Transfer of the IROI activities to on-line performance results in large risk reductions during the refueling outage and negligible risk increases while operating at power. However, human errors associated with the on-line transfer and other unknown risk factors must be studied further before this program is implemented fully at a power plant such as MP-3.

Chapter 8 -- Economic and Safety Benefits of the IROI

8.1 Introduction

Significant potential economic and safety benefits result as a consequence of implementation of the IROI. The most fundamental of these benefits will result from avoided repair and equipment replacement costs arising from the reduction of intrusive practices. The largest economic benefit, however, will arise as a result of reducing the critical path of the refueling outage. These substantial savings can in turn be a source of funding for an advanced monitoring program or enhanced safety training of personnel.

8.2 Direct Economic and Safety Benefits

The reduction of the number of inspection items associated with the ROI will provide MP-3 with immediate economic and safety benefits. Reduced maintenance, such as the increased periodicity of changing the turbocharger oil, will result in fewer basic parts being needed. The diesel operator will need items such as filters and fresh oil at a reduced frequency. Additionally, the diesel engineer can eliminate use of unnecessary test equipment, such as the fuel injector static test mechanism, from the MP-3 engineering inventory [21].

The more profound and important benefit realized directly by MP-3 will occur from the avoided safety risk associated with errors caused by humans. The less intrusive IROI will preserve the condition of the EDG eliminating unnecessary action by humans. Although failures of the EDG will still be possible, the frequency of human-induced failures is likely to decrease. These avoided failures will also likely reduce the amounts of money and time needed to repair the diesel following a such a failure [15, 21].

A good example of such failures took place during MP-3's last refueling outage. The TS require a disassembly inspection of two of the exhaust valve assemblies (one on each diesel) every 36 months. A worker damaged one of these exhaust valves so badly during disassembly that it had to be replaced by the inspection team. The other exhaust valve was also replaced by the inspection team because of pitting on the valve seating face. Although this particular valve failed its inspection due to the pitting, all of the personnel involved with the inspection stated that the valve was still fully operational (additionally, the engine analyzer had not indicated a problem with the valve) -- MP-3 replaced the equipment because of a technicality [21]. MP-3 replaced two functioning valves at a large economic and safety cost. Although this specific inspection is not included in the current ROI, it is an example of the type of inspections eliminated under the IROI.

These types of direct benefits are difficult to quantify as they depend upon past documentation. Workers at MP-3 made no attempt to record the rationale for each specific equipment replacement at MP-3. Instead EDG workers related this information on an anecdotal basis, such as the example of the exhaust valve assemblies. The inspection participants, however, feel that the direct savings realized as a result of the IROI will be substantial.

8.3 Shortened Refueling Outage Benefits

Chapter 6 details the risk benefits of a shorter refueling outage revealing the benefits as being substantial. The economic benefits of a shortened refueling outage are fortunately just as substantial. While a plant is in a refueling outage they must buy power from other sources to provide to their customers. In May of 1995, the replacement cost per day was anywhere from $215,000 to $344,000 (1995 dollars). This translates to a maximum approximates savings of $1.18 million ($344,000/day * 3.42 days) over the entire refueling outage if current DID levels are maintained by MP-3 [40].

Additionally, the shortened refueling outage will also reduce the labor costs associated with the current ROI. For the 1995 ROI, the total cost of internal and external labor was approximately $165,000 [48]. The vast majority of this was paid to Colt-Pielstick for vendor-related support. Assuming a level price per hour for all labor costs of $487 results in an additional $40,000 savings in avoided cost.

8.4 Utilization of Economic Benefits

Improved DID, decreased fuel melt probability and reduced EDG failure probability are all safety benefits of the IROI. In addition to these important safety benefits, MP-3 can use the economic benefits of the IROI to fund additional EDG monitoring equipment and training programs that benefit the safety of the plant.

For example, one particular concern of the experts at INEEL is human errors introduced during the realignment of the EDG following the ROI [15]. In many plants, a single operator will use a checklist to ensure that the EDG is ready for operation and testing. The INEEL experts have stated that a system of double checks, in which two workers are responsible for performing identical checks, will remedy the realignment errors. Funding for this additional labor can come from the avoided labor costs associated with the IROI. The two inspectors can perform this initial check and subsequent double check almost simultaneously, therefore avoiding an extension of the refueling outage.

The avoided costs of the IROI can also pay for additional sensing and monitoring of the EDG. Dulik's work outlines the economics of such a plan in detail. The result of his analysis concludes that a plant can pay for such a device with the avoided cost of just one refueling outage [3].

The substantial savings can also fund improvements in the work place for the EDG workers. An improved work space and lounge can have positive effects on the quality of work produced by laborers. The economic benefits of the IROI can also fund non-EDG related safety programs such as CPR or fire safety training.

8.5 Conclusion

The economic savings associated with the IROI are remarkable. The avoided costs of labor and equipment are substantial but are minute when compared to the millions saved through a shortened refueling outage. A plant realizes safety benefits through reduced risk at power and while the plant is refueling. A plant can experience additional safety benefits through the funding of various projects.

Chapter 9 -- Conclusions and Recommendations

The refueling outage inspection currently utilized at MP-3 has serious administrative and basic engineering shortcomings. Analysis of the ROI utilizing risk-informed performance-based methodology reveals that MP-3 can realize substantial benefits through implementation of an improved refueling outage inspection.

Chapter 4 presents a plan for the IROI based upon the opinions of the MP-3 and MP-2 diesel engineers. Both of these men have extensive experience with EDGs and the MP-3 diesel engineer has worked with the MP-3 diesels since they were put into operation. Their recommendations are based upon their inspection experience and their detailed knowledge of the performance of their respective diesels.

Chapter 5 assembles the experience of non-nuclear industry EDG applications. We compare and contrast inspections, operating experience, and expert opinion associated with EDGs in hospitals, the FAA and the US Navy. We use this comparison to further substantiate the recommendations made by the Millstone engineers.

We present the numerous risk benefits associated with the IROI in Chapter 6. Analysis of defense in depth, refueling outage fuel melt probability, and EDG failure probability all show that implementation of the IROI will result in a net risk improvement.

Chapter 7 details the risk and time savings associated with the on-line transfer of the IROI. This transfer requires an increase in the EDG allowed outage time from its current three day limit. An analysis of an AOT increase to 7 and 14 days reveals that the associated risk increase is insubstantial according to NRC and EPRI limits. MP-3 implementation of such a plan, however, is limited by operational uncertainties.

Finally, Chapter 8 presents the many economic and safety benefits associated with the IROI. The substantial economic benefits realized by MP-3 can be used to implement further safety programs within the plant.

We conclude that the refueling outage inspection of the diesel should be developed and implemented by personnel familiar with the operating characteristics and history of the individual diesels. The vendor recommendations for EDG inspection and maintenance should be used solely as a recommendation, not as a rigid set of rules. We also judge that vendor representatives should be used as consultants, not inspectors, as their role of inspector is compromised by an obvious conflict of interest.

The NRC will likely require implementation of the IROI on a trial basis if it is to proceed. MP-3 can accomplish this through application of the IROI on one EDG only. Transfer to on-line performance of the inspection would be the next proposed step taken by MP-3 following the proven success of the IROI.

We used methods and arguments in this work that demonstrate EDG regulation can be logically altered based on the performance history of the diesel and the associated risk consequences. These methods easily transfer to other questionable regulation within the nuclear industry structure.

Chapter 10 -- Future Work

10.1 Introduction

The project on *Integrated Models, Data Bases and Practices Needed for Performance-Based Safety Regulation*, of which this EDG ROI study is a part, concludes in January of 1998. Although the study provides a clear framework for the application of performance-based safety regulation, specific EDG ROI questions left unanswered in this work may also arise in future application of the methodology.

10.2 Inspection Administration

Although the current administration of the ROI is questionably set up by the TS, total elimination of inspection oversight may not be appropriate. Implementation of a diesel inspection program similar to that of the US Navy should be explored. Such a program would provide a much needed third party inspector whose primary goal would be diesel reliability and safety.

10.3 Balancing Risk Benefit

The numerous risk benefits realized through implementation of the IROI should be integrated in such a way that they provide maximum safety and reliability improvement. A detailed study of the integration of DID, fuel damage probability, and diesel reliability will provide a framework for future regulation alteration analysis.

10.4 On-line Transfer of IROI

The performance of the IROI while the plant is operating at full power promises substantial risk, economic, and safety benefits with a negligible increase in CDF. Further work must be performed, however, to determine the likelihood of increased human errors caused by the on-line transfer. Additionally, compensation within the power system should be explored to adjust for the anticipated increase in the AOT of the EDG.

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Appendix A -- Millstone Unit 3 Technical Specifications

The following material is an excerpt from the NRC-approved Technical Specifications for Unit 3 of the Millstone Nuclear Power Station [18]. This specific selection outlines surveillance requirements for the electrical power systems utilized at MP-3. Technical Specification (TS) 4.8.1.1.2.g.1, located in this appendix, is repeatedly refered to throughout this work as it forms the basis for the Emergency Diesel Generator refueling outage inspection.

SURVEILLANCE REQUIREMENTS

4.8.1.1.1 Each of the above required independent circuits between the offsite transmission network and the Onsite Class 1E Distribution System shall be:

a. Determined OPERABLE at least once per 7 days by verifying correct breaker alignments, indicated power availability, and

b. Demonstrated OPERABLE at least once per 18 months during shutdown by transferring (manually and automatically) unit power supply from the normal circuit to the alternate circuit.

4.8.1.1.2 Each diesel generator shall be demonstrated OPERABLE:

a. In accordance with the frequency specified in Table 4.8-1 on a STAGGERED TEST BASIS by:

1) Verifying the fuel level in the day tank,

2) Verifying the fuel level in the fuel storage tank,

3) Verifying the fuel transfer pump starts and transfers fuel from the storage system to the day tank,

4) Verifying the lubricating oil inventory in storage,

5) Verifying the diesel starts from standby conditions and achieves generator voltage and frequency at 4160±420 volts and 60±0.8 Hz. The diesel generator shall be started for this test by using one of the following signals:

a) Manual, or

b) Simulated loss-of-offsite power by itself, or

c) Simulated loss-of-offsite power in conjunction with an ESF Acutation test signal, or

d) An ESF Actuation test signal by itself.

6) Verifying the generator is synchronized and gradually loaded in accordance with the manufacturer's recommendations to greater than or equal to 4986 kW and operates with a load greater than or equal to 4986 kW for at least 60 minutes, and

7) Verifying the diesel generator is aligned to provide standby power to the associated emergency buses.

b. At least once per 184 days, verify that the diesel generator starts and attains generator voltage and frequency of 4160 ±420 volts and 60 ±0.8 Hz within 11 seconds after the start signal. The generator shall be synchronized to the associated emergency bus, loaded to greater than or equal to 4986 kW in accordance with the manufacturer's recommendations, and operate with a load greater than or equal to 4986 kW for at least 60 minutes. The diesel generator shall be started for this test using one of the signals in Surveillance Requirement 4.8.1.1.2.a.5. This test, if it is performed so it coincides with the testing required by Surveillance Requirement 4.8.1.1.2.a.5, may also serve to concurrently meet those requirements as well.

c. At least once per 31 days and after each operation of the diesel where the period of operation was greater than or equal to 1 hour by checking for and removing accumulated water from the day tank;

d. At least once per 31 days by checking for and removing accumulated water from the fuel oil storage tanks;

e. By sampling new fuel oil in accordance with ASTM-D4057 prior to addition to storage tanks and:

1) By verifying in accordance with the tests specified in ASTM-D975-81 prior to addition to the storage tanks that the sample has:

a) An API Gravity of within 0.3 degrees at 60°F, or a specific gravity of within 0.0016 at 60/60°F, when compared to the supplier's certificate, or an absolute specific gravity at 60/60°F of greater than or equal to 0.83 but less than or equal to 0.89, or an API gravity of greater than or equal to 27 degrees but less than or equal to 39 degrees;

b) A kinematic viscostiy at 40°C of greater than or equal to 1.9 centistokes, but less than or equal to 4.1 centistokes (alternatively, Saybolt viscosity, SUS at 100°F of greater than or equal to 32.6, but less than or equl to 40.1), if gravity was not determined by comparison with the supplier's certification;

c) A flash point equal to or greater than 125°F; and

d) Water and sediment less than 0.05 percent by volume when tested in accordance with ASTM-D1796-83.

2) By verifying within 30 days of obtaining the sample that the other properties specified in Table 1 of ASTM-D975-81 except that: (1) the cetane index shall be determined in accordance with ASTM-D976 (this test is an appropriate approximation for cetane number as stated in ASTM-D975-81 [Note E]), and (2) the analysis for sulfur may be performed in accordance with ASTM-D1552-79, ASTM-D2622-82 or ASTM-D4294-83.

f. At least once every 31 days by obtaining a sample of fuel oil in accordance with ASTM-D2276-78, and verifying that total particulate contamination is less than 10 mg/liter when checked in accordance with ASTM-D2276-78, Method A;

g. At least once per 18 months, during shutdown, by:

1) Subjecting the diesel to an inspection in accordance with procedures prepared in conjunction with its manufacturer's recommendations for this class of standby service;

2) Verifying the generator capability to reject a load of greater than or equal to 595 kW while maintaining voltage at 4160 $\pm$ 420 volts and frequency at 60 $\pm$ 3 Hz;

3) Verifying the generator capability to reject a load of 4986 kW without tripping. The generator voltage shall not exceed 5000 volts during and 4784 volts following the load rejection;

4) Simulating a loss-of-offsite power by itself, and:

a) Verifying deenergization of the emergency buses and load shedding from the emergency buses, and

b) Verifying the diesel starts from standby conditions on the auto-start signal, energizes the emergency buses with permanently connected loads within 11 seconds, energizes the auto-connected shutdown loads through the load sequencer and operates for greater than or equal to 5 minutes while its generator is loaded with the shutdown loads. After energization, the steady-state voltage and frequency of the emergency buses shall be maintained at 4160 ± 420 volts and 60 ± 0.8 Hz during the test.

Appendix B -- Colt-Pielstick PC2V Engine Instructions

The following material consists of an excerpt from the Colt-Pielstick Engine Instruction manual [17]. This manual contains information covering the description, operation and servicing of the Colt-Pielstick PC2V diesel engine, the type of engines utilized at Millstone 3. The specific information contained in this appendix consists of the supplemental maintenance instructions tailored for PC2V engines used for standby service.

The Annual/Refuel instructions found in this excerpt make up the 18 month emergency diesel generator refueling outage inspection -- the focus of the work in this report.

W. SUPPLEMENT MAINTENANCE INSTRUCTIONS
For Model PC2V Standby Units

The following inspection routine is supplemental to component part operation and service instructions in the instruction book and is recommended for engine and standby nuclear service. The unit may not accumulate significant operating hours between refueling and maintenance periods but the service and importance of availability justifies the frequency of inspection.

It is of primary importance that every repair and malfunction is entered onto the engine operating log. Operating log data must be used to graph critical pressures and temperatures to determine trends in operating performance. It is of equal importance that this data be available in the Maintenance Department for ready reference and analysis by maintenance and visiting service personnel.

Daily Inspection

1. Lube oil level in turbochargers air side and exhaust side, oil sumps, outboard bearing, governor, air distributor and air compressor. Presence of water in the oil requires determination of cause and immediate correction. Note that unlike automotive engines, oil leveling and measuring procedures are performed with the engine operating at controlled temperatures. Cold oil will expand and raise oil levels. Do not overfill as bearing damage can occur.
2. Standby heaters and pumps are operational; minimum lube oil temperature 120°F, water temperature 105°F.
3. Jacket water surge tank level. Changes in the level of the surge tank or presence of oil must be investigated and the cause corrected.
4. Control power is available, there are no flags on the switch gear controls and no annunciator alarms. The engine control should be set for operation.

Weekly or Biweekly -- Operation and Checks

1. All preceding instructions plus drain air start tank condensate.
2. Operate rocker prelube pump 5 minutes if engine is not operated every week.
3. Check injection pump racks for free movement. Clean injection pump racks with fuel oil as required.
4. Check the DC control supply and service batteries as required.
5. Check day tank fuel level and inspect tank pit for fuel leakage.
6. Unit operation
   a. During run-in of replacement parts and performance checks other than emergency starts, it is desirable to start the engine at idle speed, increase the speed over a 5 to 10 minute period to 514 rpm and apply load over a

10 to 30 minute period. As with an automobile, moderate treatment improves longevity. Actual run-in procedures vary depending upon part replacement and will be provided by our service representative.

b. Surveillance Test (Weekly or Biweekly)

After confirmation that the unit is ready for start, proceed with test start in less than 10 seconds.

-Run the unit at no load for 3 to 5 minutes, until fluid pressures and temperatures are stabilized.

-Apply 20 to 30 percent load and run the unit for 3 to 5 minutes, until pressures and temperatures are stabilized.

-Apply additional load to bring the unit to 50 to 60 percent of continuous rating. Run the unit for 3 to 50 minutes, until pressures and temperatures are stabilized.

-Apply additional load to bring the unit to 80 to 90 percent of continuous rating.

c. Operate the unit 1 to 2 hours. Temperature and pressure data should be recorded after startup and after 1 hour operation. The second line of data will reflect stabilized temperatures and should be plotted to indicate possible changes in performance. If the unit is run for more than one hour, a line of data should be recorded every hour.

d. Wipe down the unit and clean the area noting any oil, fuel or water minor leaks in need of repair. Unusual heat on bearing housings should be investigated. Site glasses for flow and levels should be rechecked.

e. Check generator field slip ring brushes for arcing.

f. Record lube oil usage.

g. Reduce load gradually, at same rate as the loading reference described in paragraph b above. Operate unit 2 to 3 minutes at no load for cool down prior to engine shutdown.

h. Analyze operating data to determine if maintenance is required or if temperature or pressure data requires further investigation. Jacket water, lube oil, air manifold, raw water, fuel oil and exhaust temperatures and pressures should remain relatively constant for any given load. Changes in temperatures or pressures or differentials in temperatures or pressures generally means a change in operating condition of the engine and the causes should be determined.

i. Surveillance tests loading should always be the same to provide for comparison of engine operating data and determine if preventive maintenance is required.

Quarterly

1. All preceding instruction.
2. Service all the auxiliaries, such as the starting air compressor, lube oil filter and strainer as required and check the condition of the air inlet filters.
3. Sample the jacket water for the required level of treatment.

4. Sample the lube oil for condition and contaminates. Check and add approved oil as required to the alternator bearing, governor and turbochargers.
5. Check all pump seals for excessive leakage.
6. Check and observe engine during starting for air leakage in piping, servo and controls.
7. Sample check rockers. Remove rocker box cover, check for proper lubrication, tappet clearance and confirm no water is leaking into the rocker arm compartment.
8. Thoroughly clean engine room.

Annual/Refuel: (1 year -- 18 months)

1. All preceding instructions.
2. Remove and check injection nozzles for operation and opening pressure.
3. Remove, disassemble, clean and repair all air start valves and air start distributors. Clean/replace air start distributor filter.
4. Drain and refill governor and turbochargers with approved oil.
5. Drain, flush and refill outboard bearing with approved oil.
6. Check tightness on all foundation block to base, oil and water line bolts.
7. Check sample of rocker lube oil for condition and contaminants.
8. Check turbocharger inlet casing and turbo casing water passages for scale. The inside surface of these casings is the best indication for adequacy of water treatment.
9. Check for tightness of exhaust manifold flange bolts to cylinder head (165-196 ft.lbs.).
10. Check all safety and shutdown controls for appropriate pressures and temperatures.
11. Borescope all cylinder liners.
12. Inspect the crankcase end of all cylinder liners.
13. Check main bearing cap tightness (9950-1100 psi hydraulic) and side bolts (hammer tight). Alternately confirm cap tightness to frame and saddle to .0015 feeler gauge.
14. Visually examine gear train and drives, cam shafts and bearing, push rods and rocker arms.
15. Check crankshaft alignment and bearing clearances.
16. Check connecting rod bearing clearances with feeler gauge.
17. Inspect all ledges and corners in crankcase for debris which could indicate other mechanical problems. Confirm all cotters, safety wire and lock tabs are in place and tight.
18. Water test engine and inspect for internal and external leaks. Isolate J.W. surge tank and test entire system at 40 psi. After engine is returned to operation and has reached normal operating temperature, remove each rocker cover and inspect for water leaks at top area of cylinder head.
19. Check alternator coils and poles for indication of movement (visual).
20. Drain and refill alternator bearing lube sump. If oil has contaminants, pull bearing cap and inspect journal.

21. Inspect and clean (if required) overspeed trip mechanism. Check operation according to overspeed trip test instructions.

Biannually (2 - 3 years)

1. All preceding instructions.
2. Gear Train
   a. Check backlash (.2 - .4 mm/ .008 - .016 inches).
   b. Check camshaft flexible drive locking plate capscrews for indication of loosening (sheared locks). Tighten and relock if required.
3. Check fuel control linkage roll pins for tightness. Replace worn parts.
4. Remove one pair of exhaust valve cage assembly, inspect and repair if required. It is recommended that the valve selection be made by the serviceman and based on engine operating data.

The above recommendations are basic and may be altered dependent upon site experience. Deletions and/or additions may be made depending upon site operating history. The five year inspection should be reviewed with the factory.

Appendix C -- Millstone Unit 3 EDG System Basic Events and Fault Tree

The following material is a summary of the fault tree information used in the Probabilistic Risk Assessment of Millstone 3 [50].

Table C.1 includes a listing of the basic events which are used in the MP-3 fault tree. Each basic event description is accompanied by its corresponding rate, exposure, and probability of occurance.

Figure C.1 includes those segments of the Millstone 3 EDG system fault tree that are affected by changes to the EDG refueling outage inspection. A complete fault tree can be located in Dulik's report[3].

Event #	Description	Rate	Exposure	Probability
1	BATTERY CHARGER 1 FAILS DURING OPERATION	7.000e-06	8760	6.132e-02
2	DC PANEL 301A-1 BUS FEED BREAKER FAILS TO REMAIN CLOSED	1.520e-06	8760	1.332e-02
3	DC PANEL 301A-1 BUS FEED BREAKER FAILS TO REMAIN CLOSED	1.520e-06	8760	1.332e-02
4	METAL ENCLOSED DC BUS 301A1 BUS-TO-TO-GROUND SHORT	2.000e-07	8760	1.752e-03
5	LOSS OF OFFSITE POWER	1.000e+00	0.041	4.100e-02
6	(INIT) EXPANSION JOINT EXJ1A RUPTURES	8.480e-08	8760	7.428e-04
7	(INIT) EXPANSION JOINT EXJ1C RUPTURES	8.480e-08	8760	7.428e-04
8	(INIT) MOTOR OPERATED VALVE V102A FAILS TO REMAIN OPEN	1.400e-07	8760	1.226e-03
9	(INIT) MOTOR OPERATED VALVE V102C FAILS TO REMAIN OPEN	1.400e-07	8760	1.226e-03
10	(INIT) CCF OF SERVICE WATER PUMPS 'A' AND 'C' FAILS TO RUN	3.200e-05	876	2.803e-02
11	(INIT) SERVICE WATER PUMP SWP1A FAILS TO RUN	3.200e-05	8760	2.803e-02
12	(INIT) SERVICE WATER PUMP SWP1C FAILS TO RUN	3.200e-05	8760	2.803e-02
13	SERVICE WATER OUTLET VALVE AOV39A FAILS TO OPEN ON DEMAND	2.000e-03	1	2.000e-03
14	BUS FEED BREAKER 32T1-2 FAILS TO REMAIN CLOSED	1.520e-06	24	3.648e-05
15	BUS FEED BREAKER 32T4-2 FAILS TO REMAIN CLOSED	1.520e-06	24	3.648e-05
16	BUS FEED BREAKER 32T6-2 FAILS TO REMAIN CLOSED	1.520e-06	24	3.648e-05
17	34A TO 34C BUS TIE BREAKER 34C-1T-2 FAILS TO OPEN ON DEMAND	1.580e-04	6	9.480e-04
18	BUS FEED BREAKER 34C3-2 FAILS TO REMAIN CLOSED	1.520e-06	24	3.648e-05
19	TRANSFER PUMP *P1A '42 BREAKER' FAILS TO CLOSE	3.380e-04	1	3.380e-04
20	TRANSFER PUMP *P1C '42 BREAKER' FAILS TO CLOSE	3.380e-04	1	3.380e-04
21	BUS FEED BREAKER TO 34C AUX CIRCUIT FAILS TO REMAIN CLOSED	1.520e-06	24	3.640e-05
22	'42 BREAKER' FOR *FN1A FAILS TO CLOSE ON DEMAND	3.380e-04	1	3.380e-04
23	'42 BREAKER' FOR *FN1C FAILS TO CLOSE ON DEMAND	3.380e-04	1	3.380e-04
24	DIESEL GENERATOR A OUTPUT BREAKER FAILS TO CLOSE ON DEMAND	3.380e-04	1	3.380e-04
25	FAILURE TO SHED MAJOR EQUIP. LOADS (BREAKER FAILS TO OPEN)	1.580e-04	30	4.740e-03
26	METAL ENCLOSED AC BUS-TO-GROUND SHORT (BUS 32T)	2.000e-07	24	4.800e-06
27	METAL ENCLOSED AC BUS-TO-GROUND SHORT (BUS 34C)	2.000e-07	24	4.800e-06
28	METAL ENCLOSED AC BUS-TO-GROUND SHORT (MCC 32-1T)	2.000e-07	24	4.800e-06
29	METAL ENCLOSED AC BUS-TO-GROUND SHORT (MCC 32-5T)	2.000e-07	24	4.800e-06
30	METAL ENCLOSED BUS VIAC-1 BUS-TO-GROUND SHORT	2.000e-07	24	4.800e-06
31	CONTACT PAIR 27R56 FAILS TO CLOSE	1.350e-04	6	8.100e-04
32	CONTACT PAIR 27Y12 FAILS TO CLOSE	1.350e-04	6	8.100e-04
33	CONTACT PAIR 62V13 FAILS TO CLOSE	1.350e-04	6	8.100e-04
34	CONTACT PAIR 62W15 FAILS TO CLOSE	1.350e-04	6	8.100e-04
35	CONTACT PAIR 62Y62FAILS TO CLOSE	1.350e-04	6	8.100e-04
36	CONTACT PAIR 3A-3EGS*EG-A CA1-CB1 FAILS TO CLOSE	1.350e-04	6	8.100e-04
37	CONTACT PAIR 3A-3EGS*EG-A CC1-CD1 FAILS TO CLOSE	1.350e-04	6	8.100e-04
38	DIESEL GENERATOR A UNAVAILABLE DUE TO TEST OR MAINTENANCE	1.100e-02	1	1.100e-02
39	EDG A FAILS TO START ON DEMAND (INCLUDES FAILURE TO RUN)	1.640e-02	1	1.640e-02
40	OUTLET DAMPER 20A FAILS TO OPEN	4.000e-03	1	4.000e-03
41	OUTLET DAMPER 20C FAILS TO OPEN	4.000e-03	1	4.000e-03
42	INLET DAMPER 23A FAILS TO OPEN	4.000e-03	1	4.000e-03
43	RECIRC DAMPER 26A FAILS TO CLOSE	4.000e-03	1	4.000e-03
44	EDG LOAD SEQUENCER 'A' FAILS ON DEMAND	1.000e+00	7.580e-04	7.580e-04
45	FAN UNIT *FN1A FAILS TO RUN	7.890e-06	24	1.894e-04
46	FAN UNIT *FN1A FAILS TO START	4.840e-04	1	4.840e-04
47	FAN UNIT *FN1A OUT OF SERVICE FOR MAINTENANCE	5.660e-04	1	5.660e-04
48	FAN UNIT *FN1C FAILS TO RUN	7.890e-06	24	1.894e-04
49	FAN UNIT *FN1C FAILS TO START	4.840e-04	1	4.840e-04
50	FAN UNIT *FN1C OUT OF SERVICE FOR MAINTENANCE	5.660e-04	1	5.660e-04
51	FUSE VIAC1 FAILS TO REMAIN CLOSED	5.000e-07	24	1.200e-05
52	DC TO AC POWER INVERTER-1 FAILS DURING OPERATION	2.000e-05	24	4.800e-04

Table C.1 Basic Events

Event #	Description	Rate	Exposure	Probability
53	LEVEL SWITCH LS40A FAILS TO OPERATE (LOW DAY TANK LEVEL)	1.000e -05	1	1.000e -05
54	LEVEL SWITCH LS41A FAILS TO OPERATE (LOW-LOW DAY TANK LEVEL)	1.000e-05	1	1.000e-05
55	FUEL OIL TRANSFER PUMP *P1A FAILS TO RUN	2.500e-05	24	6.000e-04
56	FUEL OIL TRANSFER PUMP *P1A FAILS TO START	2.000e-03	1	2.000e-03
57	FUEL OIL TRANSFER PUMP *P1C FAILS TO RUN	2.500e-05	24	6.000e-04
58	FUEL OIL TRANSFER PUMP *P1C FAILS TO START	2.000e-03	1	2.000e-03
59	RELAY COIL 27Y2 FAILS TO ENERGIZE	1.000e-04	6	6.000e-04
60	RELAY COIL 27R FAILS TO DEENERGIZE	1.000e-04	6	6.000e-04
61	RELAY COIL 62V FAILS TO ENERGIZE	1.000e-04	6	6.000e-04
62	RELAY COIL 62W FAILS TO ENERGIZE	1.000e-04	6	6.000e-04
63	RELAY COIL 62Y FAILS TO ENERGIZE	1.000e-04	6	6.000e-04
64	FUEL OIL STORAGE TANK TK1A RUPTURES	1.000e-07	24	2.400e-06
65	FUEL OIL DAY TANK TK2A RUPTURES	1.000e-07	24	2.400e-06
66	TRANSFORMER 34C3-1X FAILS TO OPERATE	1.200e-06	24	2.880e-05
67	TEMPERATURE SWITCH TS32A FAILS TO OPERATE	2.000e-04	1	2.000e-04
68	CCF - SW AIR OPERATED VALVES *39A, B FAIL TO OPEN ON DEMAND	2.000e-03	0.068	1.360e-04
69	CCF OF DGs TO START ON DEMAND (INCLUDES FAILURE TO RUN)	1.640e-02	0.068	1.115e-03
70	CCF TO RUN OF TRANSFER PUMPS *P1A AND *P1C	2.500e-05	2.4	6.000e-05
71	CCF TO START OF TRANSFER PUMPS *P1A AND *P1C	2.000e-03	0.1	2.000e-04
72	DC PANEL 301A-1A BUS FEED BREAKER FAILS TO REMAIN CLOSED	1.520e-06	24	3.648e-05
73	DC PANEL 301A-1B BUS FEED BREAKER FAILS TO REMAIN CLOSED	1.520e-06	24	3.648e-05
74	DC PANEL 301A-1 BUS FEED BREAKER FAILS TO REMAIN CLOSED	1.520e-06	24	3.648e-05
75	DC BUS 301A-1 FEED BREAKER TO INV1 FAILS TO REMAIN CLOSED	1.520e-06	24	3.648e-05
76	METAL ENCLOSED DC BUS-TO-GROUND SHORT (DC PANEL 301A-1)	2.000e-07	24	4.800e-06
77	METAL ENCLOSED DC BUS 301A-1A BUS-TO-GROUND SHORT	2.000e-07	24	4.800e-06
78	METAL ENCLOSED DC BUS 301A-1B BUS-TO-GROUND SHORT	2.000e-07	24	4.800e-06
79	STORAGE BATTERY 301A-1 FAILS TO PROVIDE OUTPUT ON DEMAND	5.000e-04	1	5.000e-04
80	'42 BREAKER' FOR VENTILATION UNIT HVY*FN2A FAILS TO CLOSE	3.380e-04	1	3.380e-04
81	AIR OPERATED DAMPER *23A FAILS TO OPEN	2.000e-03	1	2.000e-03
82	VENTILATION UNIT HVY*FN2A FAILS TO RUN	7.890e-06	24	1.894e-04
83	VENTILATION UNIT HVY*FN2A FAILS TO START	4.840e-04	1	4.840e-04
84	TEMPERATURE SWITCH TS60A FAILS TO OPERATE	2.000e-04	1	2.000e-04
85	CCF - AIR OPERATED DAMPERS *23A AND *23B FAIL TO OPEN	2.000e-03	0.068	1.360e-04
86	CCF - VENTILATION UNITS HVY*FN2A, FN2B FAIL TO RUN	7.890e-06	2.4	1.894e-05
87	CCF - VENTILATION UNITS HVY*FN2A, FN2B FAIL TO START	4.840e-04	0.1	4.840e-05
88	NOT SUMMER OPERATION	1.000e+00	0.75	7.500e-01
89	PUMP SWP*P1A START CIRCUIT BREAKER FAILS TO CLOSE ON DEMAND	3.380e-04	1	3.380e-04
90	PUMP SWP*P1C START CIRCUIT BREAKER FAILS TO CLOSE ON DEMAND	3.380e-04	1	3.380e-04
91	BUS FEED BREAKER FOR V102A FAILS TO CLOSE ON DEMAND	3.380e-04	1	3.380e-04
92	BUS FEED BREAKER FOR V102C FAILS TO CLOSE ON DEMAND	3.380e-04	1	3.380e-04
93	PUMP 'A' CONTACT PAIR 52S 53-54 FAILS TO CLOSE	1.350e-04	132	1.782e-02
94	PUMP 'C' CONTACT PAIR 52S 53-54 FAILS TO CLOSE	1.350e-04	132	1.782e-02
95	LOW HEADER PRESSURE CONTACT PAIR 63X12 FAILS TO CLOSE	1.350e-04	132	1.782e-02
96	LOW HEADER PRESSURE CONTACT PAIR 63X56 FAILS TO CLOSE	1.350e-04	132	1.782e-02
97	PUMP 'C' LUBRICATION FAILS (CHECK VALVE - 768 FAILS TO OPEN)	2.000e-04	1	2.000e-04
98	PUMP 'A' LUBRICATION FAILS (CHECK VALVE - 769 FAILS TO OPEN)	2.000e-04	1	2.000e-04
99	CHECK VALVE P1A*V7 FAILS TO OPEN ON DEMAND	2.000e-04	1	2.000e-04
100	CHECK VALVE P1C*V5 FAILS TO OPEN ON DEMAND	2.000e-04	1	2.000e-04
101	MOTOR OPERATED VALVE V102A FAILS TO OPEN ON DEMAND	4.000e-03	1	4.000e-03
102	MOTOR OPERATED VALVE V102C FAILS TO OPEN ON DEMAND	4.000e-03	1	4.000e-03
103	SERVICE WATER PUMP SWP1A OOS FOR MAINTENANCE	1.100e-02	1	1.100e-02

Table C.1 Basic Events (continued)

Table C.1 Basic Events (continued)

Event #	Description	Rate	Exposure	Probability
104	SERVICE WATER PUMP SWP1A FAILS TO RUN	3.200e-05	24	7.680e-04
105	SERVICE WATER PUMP SWP1A FAILS TO START ON DEMAND	2.400e-03	1	2.400e-03
106	SERVICE WATER PUMP SWP1C OOS FOR MAINTENANCE	9.000e-04	1	9.000e-04
107	SERVICE WATER PUMP SWP1C FAILS TO RUN	3.200e-05	24	7.680e-04
108	SERVICE WATER PUMP SWP1C FAILS TO START ON DEMAND	2.400e-03	1	2.400e-03
109	SERVICE WATER TRAIN 'A' PUMP 'A' IN LEAD	1.000e+00	0.5	5.000e-01
110	SERVICE WATER TRAIN 'A' PUMP 'C' IN LEAD	1.000e+00	0.5	5.000e-01
111	PRESSURE SWITCH PS27A FAILS TO OPERATE	2.000e-04	132	2.640e-02
112	CCF OF CHECK VALVES V5 AND V7 FAILS TO OPEN ON DEMAND	2.000e-04	0.068	1.360e-05
113	CCF OF LUBE LINE CHECK VALVES V768 AND V769 TO CLOSE	2.000e-04	0.068	1.360e-05
114	CCF OF ALL 4 LUBE LINE CHECK VALVES TO OPEN	2.000e-04	0.00029	5.800e-08
115	CCF OF ALL 4 DISCHARGE CHECK VALVES TO OPEN	2.000e-04	0.00029	5.800e-08
116	CCF OF MOTOR OPERATED VALVES 102A AND 102C FAILS TO OPEN ON DEMAND	4.000e-03	0.068	2.720e-04
117	CCF OF ALL 4 DISCHARGE MOTOR OPERATED VALVES TO OPEN	4.000e-03	0.00029	1.160e-06
118	CCF OF ALL 4 SERVICE WATER PUMPS TO START	2.400e-03	0.0022	5.280e-06
119	CCF OF SERVICE WATER PUMPS 'A' AND 'C' FAIL TO RUN	3.200e-05	2.4	7.680e-05
120	CCF TO START OF SW PUMPS 'A' AND 'C'	2.400e-03	0.1	2.400e-04
121	OPERATOR FAILS TO START FOLLOW PUMP	1.000e+00	0.01	1.000e-02

Table C.1 Basic Events (continued)

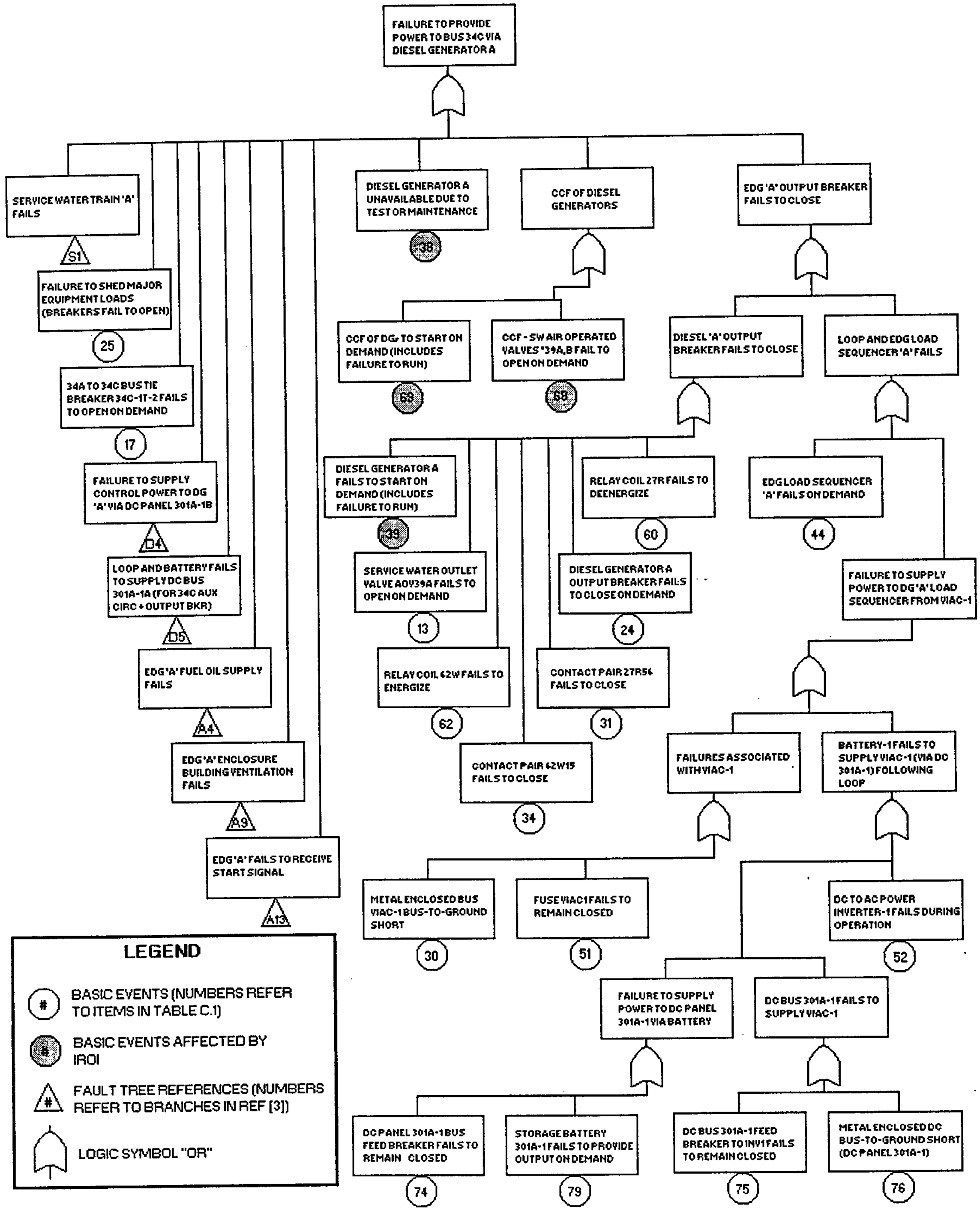

Figure C.1 MP-3 EDG Fault Tree